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HACKENSACK MEADOWLANDS AIR POLLUTION STUDY. DEVELOPMENT AND VALIDATION OF A MODELING TECHNIQUE FOR PREDICTING AIR QUALITY LEVELS

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Environmental Research and Technology, Incorporated

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16. ABSTRACT

The Hackensack Meadowlands Air Pollution Study consists of a summary report and five task reports. The summary report discusses the procedures developed for considering air pollution in the planning process and the use of these procedures to evaluate four alternative land use plans for the New Jersey Hackensack Meadowlands for 1990. The task reports describe (1) the emission projection methodology and its application to the Hackensack Meadowlands; (2) the model for predicting air quality levels and its validation and calibration: (3) the evaluation and ranking of the land use plans; (4) the planning guidelines derived from the analysis of the plans; and, (5) the software system.

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PREFACE

The Hackensack Meadowlands Air Pollution Study final report consists of a summary report, five task reports, and three appendices, each bound separately. This report is the second of the five task reports. Its purpose is to describe the mathematical basis for predicting air quality levels for the New Jersey Hackensack Meadowlands. The report discusses both the development of the model and its validation and calibration. The preparation of model emissions input data is discussed extensively in the first task report, and the procedures for operating the software components of the model are discussed in the fifth task report.

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The cooperation and assistance of the many personnel from EPA and NJDEP contributed greatly to the success of this study. The special assistances of Mr. Roland S. Yunghans, and Dr. Edward B. Feinberg, Environmental Scientists, Office of the Commissioner, NJDEP, and Mr. John Robson, Land Use Planning Branch, Office of Air Programs, EPA, is appreciated.

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SUMMARY

This report describes the development and validation of the atmospheric diffusion model used as the tool for calculating the air quality concentration patterns expected in the Meadowlands planning area in 1990. The model has been designed specifically to operate on the computing equipment of the New Jersey Department of Health, and the model has been specialized to provide input data to the ERT/AQUIP program for the evaluation of total anticipated air quality impact. Thus the model is useful both as a stand-alone tool and as an element within the framework of a total land use planning-air pollution impact evaluation system.

The model was run for validation and calibration purposes for summer, winter and annual time periods using meteorological input data from Newark Airport and the point, line and area source emission inventory developed for the year 1969. Initial comparison of the model results with measured data indicated that the accuracy could be improved by some modifications to the model.

Specific modifications made to the model included the adoption of a half-life for SO_2 emissions, the inclusion of dispersive spread statistics more characteristic of urban areas, and incorporation of wind speed variations with height above ground. The final calibration of the model utilized pollutant measurement data from five stations surrounding the Meadowlands region to develop calibration factors applicable to the individual locations and for the Meadowlands region in general.

The diffusion model development and validation has followed "standard" procedures wherever possible. This was done both to assure the future usefulness of the model in the Meadowlands area, and to establish a methodology which might be copied, and improved upon, in future related studies.

1. INTRODUCTION

Definition of the Problem

The basic goal of the model development and validation effort has been the calculation of seasonal and annual average concentrations for the pollutants of interest (SO_2, CO, NO_x, hydrocarbons and particulates) expected within the planning region for the emission patterns associated with various possible land use distributions which may exist in 1990.

An important secondary goal has been the documentation and reporting of the modeling and validation schemes for two purposes: (1) so that the model and its associated data might be used for future studies of expected air pollution impact in the Meadowlands area; and (2) so that the experience gained in the present applications study might be made available for similar studies in other regions.

The model used in this study has been developed from the basic form described by Martin and Tikvart (1968), and documented in the report on the Air Quality Display Model (NAPCA, 1969). To preserve standard model notation wherever possible, the definitions of model parameters and variables adopted in the AQDM have been retained. However, several modifications to the Martin-Tikvart model have been incorporated into this study. The modifications provide for controllable computational accuracy (as a function of computation time and therefore cost), and increased flexibility in the treatment of area sources of various geometrical shapes. These model features are particularly desirable for planning studies, where many different combinations of emission patterns must be evaluated. The details of the model adopted for use in this study are described in Section 2.

The model analysis incorporates several types of data: emission patterns, meteorological data and topographical data are required as model inputs, and air quality measurements are required for model validation and for the development of calibration parameters where appropriate. The details of the data requirements, and a summary of the data selected for use in this study, are described in Section 3.

Section 4 contains a description of the model validation scheme adopted for use in the planning projections. Various other validation techniques which were considered but not used are also described, because they may have application in similar studies for other regions.

Section 5 contains a summary statement on the modeling procedures adopted for use in preparing projections of concentration levels expected in the planning region by 1990.

2. DESCRIPTION OF THE DISPERSION MODEL

2.1 General Comments

The model used for the dispersion calculations is called MARTIK in the ERT program library. It is a gaussian plume model which follows the physical and mathematical basis described by Martin and Tikvart (1968). The model has been modified to improve computational accuracy for receptors near source areas, to permit tradeoffs between accuracy requirements and computation time, and to permit improved flexibility in the treatment of rectangular area sources of any size and location.

The model has also been specially modified to permit its use on the RCA SPECTRA 70 computer operated by the New Jersey Department of Health. Specially designed data storage and data flow routines have been developed to comply with the core limitations of the SPECTRA 70. Also, the model input and output routines have been integrated into the AQUIP software system (for example, the LANTRAN program which computes emissions source distributions from given planning parameters, and the SYMAP computer graphics program, which provides general display capabilities for land use, emissions and air quality data).

Detailed descriptions of all programs, including the version of the MARTIK program used in the present study, are presented in the User's Manual document. Readers interested in detailed reviews or operational use of the model should refer to the User's Manual, as a supplement to the following text.

The general MARTIK program provides for calculations both in an averaging mode and in an instantaneous mode. In the instantaneous case,

fixed values of the meteorological parameters (wind speed and direction, and stability class) are used, to determine the concentration pattern expected at a specific time. The description of the model in this section is restricted to the time-average mode, because the planning forecasts required are the seasonal and annual average cases.

2.2 Principal Modifications Incorporated in the ERT/MARTIK Model

The principal modifications of the basic model reported by Martin and Tikvart (1968), incorporated into the ERT/MARTIK model are listed here.

1. Treatment of Area-Source Emissions

A major improvement of accuracy of representation was made by replacing the virtual point source approximation to area source emissions with a numerical integration procedure over the area source. The use of a virtual point source representation for area sources results in a "sawtooth" concentration profile in the crosswind direction at short distances downwind from a group of area source cells. The numerical integration scheme avoids this difficulty. The integration is accomplished by summation of elemental strips of the area source and may be used for any specified source height and any wind direction. For efficiency of calculation, the computation routine uses fewer elemental strips when the source receptor distance is large and where finer elements would not significantly change the computed concentrations. The maximum number of elemental strips to be used is externally specified as part of a set of input parameters which control computational accuracy.

2. Treatment of Line-Source Emissions

Emissions from roadways may be represented as if from line-type sources. In order to estimate the downwind concentration from these sources for any

possible wind direction and elevation, another numerical integration routine was developed. This procedure involves approximating short segments of the line representation with upwind virtual point sources. In a manner similar to that of the area source integration, the number of virtual points per unit length used depends upon the distance to the receptor and the accuracy selected.

3. Flexibility of Operating Mode and Output Format

A major feature of the MARTIK system is the ability to isolate the contributions to the concentration at receptors by simple choices of input parameters. Thus, for example, the contributions from individual sources, wind directions or stability classes may be easily isolated.

4. Computational Efficiency Features

In addition to the controlled accuracy capabilities discussed in terms of the integration routines for line and area type sources, a number of other specific improvements have been made to keep computation time low. These include: (1) input specification of argument value ranges for which exponentials may be approximated by simple functions; (2) simple inverse scaling of concentration contributions as a function of wind speed, for sources with zero effective plume rise; (3) optimization of the number of source-receptor geometry calculations for a given run.

2.3 Basis of the Model: The Gaussian Plume Equation

The model calculations are based upon multiple applications, and integrated forms, of the gaussian plume equation which represents the concentra-

tion pattern downwind from a point source. The general form of the equation is

$$\chi(0,0,z) = \frac{q(x,y,H)}{2\pi\sigma_y\sigma_z u} \exp\left[-1/2\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \left\{ \exp\left[-1/2\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-1/2\left(\frac{z+H}{\sigma_z}\right)^2\right] \right\} \quad (1)$$

where

(x,y,z) are the (upwind, cross-wind and vertical) components of a cartesian coordinate system, such that the receptor point is located at or vertically above the origin (expressed in units of length) and the source at the point (x,y,H)

H is the effective height of emission and therefore the centerline height of the plume (length)

q is source strength (mass/time)

σ_y, σ_z are dispersion coefficients that are measures of cross-wind and vertical plume spread. These two parameters are functions of downwind distance and atmospheric stability (length)

u is average wind speed (length/time)

Figure 1 illustrates the geometry for the plume equation. The source base is at $z = 0$ in the coordinate system, and the plume center-line reaches an equilibrium height H at some distance downwind from the source.

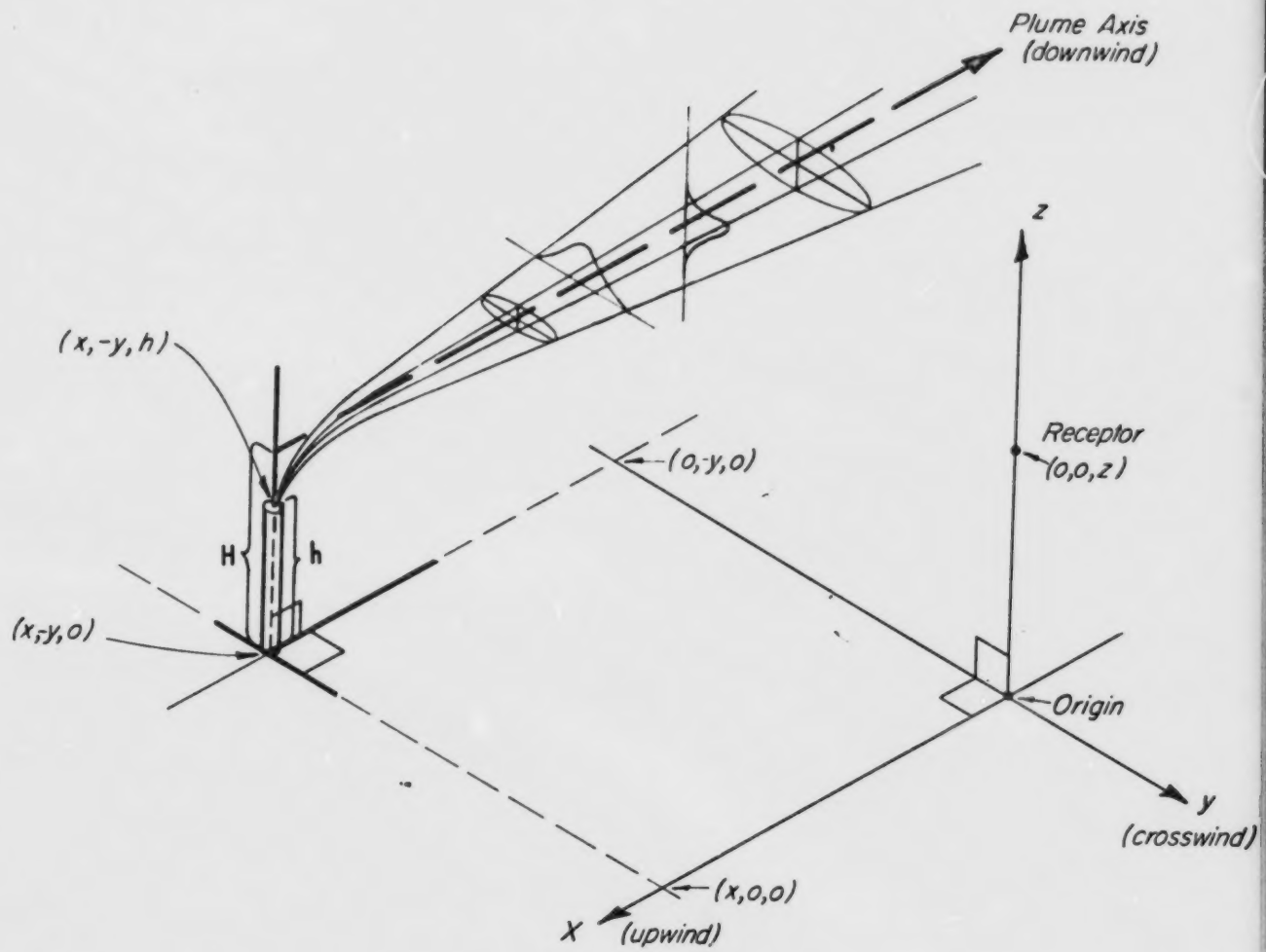


Figure 1 Coordinate System Showing Gaussian Distributions in the Horizontal and Vertical

The most important assumptions upon which the equation is based are the following:

1. The wind speed and direction in the vicinity of the point source are constant throughout the period of interest.

2. When the effluent enters the atmosphere, the plume rises until it reaches an equilibrium altitude; the plume centerline height remains constant at all downwind distances after the equilibrium height, is reached.

3. At any downwind distance, the maximum concentration occurs at the plume centerline. The distribution of concentration values off the centerline is given by the product of two gaussian, or bell-shaped curves.

4. The concentration profiles described by the gaussian form are not "instantaneous" plume profiles. Instead they represent concentrations averaged over a short time, such as 10 minutes.

5. None of the effluent is lost from the plume. Therefore when the plume boundary intersects the ground surface, it is assumed that all material is reflected back above the ground.

6. The effluent emission rate is constant, and the meteorological parameters determining plume form are constant; (i.e., the equation represents steady state conditions).

Ground-level concentration estimates are obtained by setting z = 0 in Eq. (1), resulting in

$$\chi(0,0,H) = \frac{q}{\pi \sigma_y \sigma_z u} \exp\left[-1/2 \left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-1/2 \left(\frac{H}{\sigma_z}\right)^2\right]. \qquad (2)$$

Eq. (2) can be modified to yield estimates of long-term average concentrations (e.g., seasonal and annual concentrations), when applicable stability wind rose data are available. A stability wind rose is a tabulation of the joint frequency of occurrence of wind speed, wind direction and atmospheric stability category at a specific location.

Although the probability of all wind directions is a continuous function over the long time periods, for computation purposes discrete wind directions are specified with respect to a 16-point compass, corresponding to 22.5^{o} angular sectors. For annual periods it is often assumed that all wind directions within a given 22.5^{o} sector occur with equal frequency. Thus the effluent could be assumed to be uniformly distributed in the horizontal within the sector. However, this assumption would result in discontinuities in calculated concentrations at sector boundaries. A more reasonable distribution is obtained by using a linear interpolation between sector center lines. In this case, the concentration at a given receptor location is composed of proportional contributions from both the sector containing the receptor and from the nearest adjacent sector. The linear interpolation term is given by

$$K(c-y)/c,$$

where

y = crosswind distance between the receptor and the sector centerline

c = sector width at the receptor location = $2x \tan (11.25^{o})$ = $0.398x$

K = a constant to be determined

The geometry of the interpolation is illustrated in Figure 2. Note that an SSW wind affects the receptor to the NNE of the source.

The linear interpolation is applied to the crosswind integrated form of the ground level plume equation, and the constant K is determined by the condition that, when the frequency of occurrence of wind direction is the same in all 16 sectors, the long time average concentration at any given downwind distance away from the source must be the same, regardless of direction. Therefore,

$$K = \sqrt{\frac{\pi}{2}} \frac{\sigma_y}{c},$$

and the time-averaged equation used in the computations becomes

$$\chi = \frac{Q}{\sqrt{2\pi}\sigma_z u} \left(\frac{c-y}{c^2} \right) \exp \left[-1/2 \left(\frac{H}{\sigma_z} \right)^2 \right]. \qquad (3)$$

It should be noted that Eq. (3) is different from the analogous equation in AQDM by a factor of $(2\pi x/16)/c \approx 0.99$.

Vertical diffusion of the plume is inhibited by the existence of a stable atmospheric layer having a base lower than the effective stack height (the layer elevation will generally range between 100 and 3,000 feet). The rate of vertical mixing is greatly reduced in such a layer, and the base of the layer can thus be considered as an effective "lid" on vertical transport of pollutants.

When an elevated stable layer occurs locally, the estimated pollutant concentrations can be calculated with the assumption that all the effluent remains within a mixing layer depth D defined as the vertical distance from the ground to the base of the stable layer. For the model calculations,

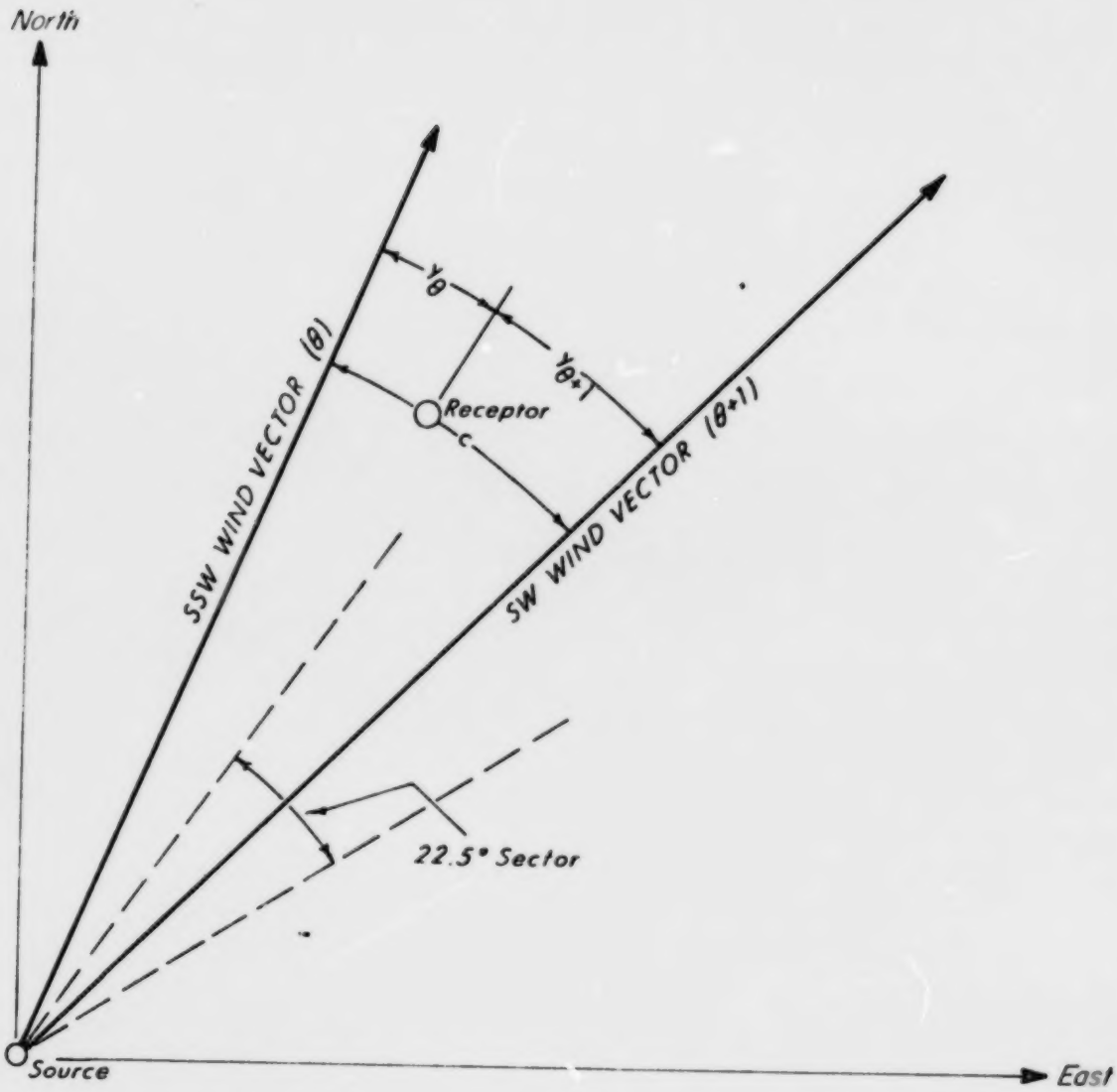


Figure 2 Geometry of the Linear Interpolation Between Adjacent Wind Direction Sectors

σ_z is considered to increase in the downwind direction until it reaches a distance x_T at which $\sigma_z = 0.47\ D$. At this distance, pollutant concentration at the base of the stable layer will be one-tenth that at the plume centerline. Up to this distance, the gaussian vertical distribution is assumed, and Eq. (3) is appropriate. At distance x_T the trapping effect of the elevated stable layer begins to be effective, and uniform mixing below the base of the stable layer is assumed to occur at downwind distance $2x_T$. For distances $x \geq 2x_T$, the average concentration is calculated with the assumption of full mixing in the mixing layer:

$$\chi = \frac{Q\,(c-y)}{Duc^2}, \tag{4}$$

For distances between x_T and $2x_T$, χ is determined by a linear interpolation between Eq. (3), evaluated at x_T and Eq. (4), evaluated at $2x_T$.

For a specific source-receptor configuration, an estimate of χ is obtained by choosing a representative wind speed for each wind speed class and solving the appropriate equation for all wind speed and stability classes appropriate for the time period in the geographical area of interest. The average concentration, $\bar{\chi}$, is obtained by summing all concentrations and weighting each one according to its frequency for the particular wind direction, wind speed class, and stability class. The average concentration is

$$\bar{\chi} = \sum_K \sum_L \sum_J F(J,K,L)\ \chi\ (J,K,L) \tag{5}$$

where

$F(J,K,L)$= normalized frequency during the period of interest for wind direction interval K, wind speed class J, and stability class L

$\bar{\chi}(J,K,L)$ = average ground-level concentration calculated from Eq. (3) or (4) as appropriate

The total concentration at a specific receptor is obtained by summing the results of Eq. (5) over all sources. For each of the 16 wind direction intervals, wind speed is defined in 6 categories and stability class in 5 categories. Thus a three-dimensional array of 480 categories is established. (However, only a few wind directions result in nonzero contributions for specific source-receptor pairs. Thus the computation time is reduced significantly.) Vertical variations in wind direction are not accounted for in the calculation of χ. (However, the ERT/MARTIK model does permit vertical variability of wind speed in both the calculation of plume rise and of average transport rates.)

The representative speeds adopted for the six climatological wind speed categories (0-3, 4-6, 7-10, 11-16, 17-21 and >21 knots), are 0.67, 2.46, 4.47, 6.93, 9.61 and 12.52 meters per second. (A modification of the 0.67 value to 0.89 was later made for purposes of model validation. This subject is discussed later in this report.)

The five stability categories (L= 1,2,3,4 and 5, in order of increasing atmospheric stability) are derived from surface level meteorological observations, as defined by Turner (1964). Stability in the lowest part of the atmosphere is determined primarily by the net heating (or cooling) of the

ground surface, and by local wind speed. Turner's classification is based upon surface wind speed, cloud cover and ceiling, supplemented by solar elevation data (latitude, time of day, and time of year); thus the stability estimates can be obtained for any Weather Bureau station at which continuous surface level observations have been made.

The values of σ_z (x,L) used in the program are those of McElroy and Pooler (1968). For computation these are represented in the power law form

$$\sigma_z = k \cdot x^d,$$

where

x is the downwind distance in meters

and

k and d are functions of the Stability Class L as given in Table 1.

TABLE 1

L =	1	2	3	4	5
k =	.072	.072	.169	1.07	1.01
d =	1.22	1.22	1.01	.682	.554

The minimum value of x used in calculating σ_z is 100 meters. When $x < 100$ meters, the program sets $x = 100$ meters prior to the σ_z calculation. This simulates initial mixing of the effluent by perturbed wind flow in the vicinity of the source, and it eliminates the possibility of unrealistically large values of concentration, corresponding to near-zero values of σ_z.

The mixing layer depth, D, varies greatly from season to season, day to day, and diurnally. Since it is impractical to account for all these variations, a procedure reflecting only major changes is used in the model. The procedure determines an effective mixing depth by modifying the average afternoon mixing depth values, as tabulated by Holzworth (1964), according to the stability class being considered. Stability classes L = 1,2, and 3 are afternoon conditions, with L = 1 corresponding to very unstable conditions. When L = 1, the value of D is assumed to be 50% greater than the climatological value tabulated by Holzworth; when L = 2 or 3, the climatological value is adopted. According to Turner's criteria, L = 5 can occur only when nighttime ground-based inversion conditions exist. Since a shallow layer of neutral or weak lapse conditions has been found to occur over urban areas (even with strong nocturnal surface inversions in the surrounding rural areas), a mixing depth of D = 100 meters is adopted for stability class L = 5, when this class is indicated by the Turner selection rules. The 100-meter value is based upon observations of Clarke (1969). Stability class L = 4 is a neutral stability condition which occurs either with high wind speeds during the day or with high negative net radiation during the night. The mixing depth for stability class L = 4 is taken to be 80% of the climatological value (class L = 3) and 20% of the class L = 5 value.

The effective stack height, appearing in Eq. (3) is defined as the height of the plume centerline when it becomes horizontal. Thus $h = h_s + \Delta h$, where h_s is the physical stack height and Δh is the plume rise. The effective stack height does not appear in Eq. (4) because the height of emission is immaterial after vertical mixing is complete.

Following the formulation of the Air Quality Display Model (NAPCA, 1969), the plume rise equation used in the program (when actual point sources are being considered) is due to Holland (1953). The equation is given by

$$\Delta h = \frac{V_s d}{u^*} \left[1.5 + 2.68 \times 10^{-3} P \left(\frac{T_s - T_a}{T_s}\right) d\right] \qquad (6)$$

where

V_s = stack gas-exit velocity (meters/sec)

d = stack exit diameter (meters)

P = atmospheric pressure (mb)

T_s = stack gas-exit temperature (^oK)

T_a = ambient air temperature (^oK)

and

u^* = mean wind speed at stack height h_s (meters/sec)

The mean wind speed at stack height (instead of the surface wind) is used in the calculation of plume rise for all calculations. For short stacks, and for line and area sources, this correction is not important, but it is significant for elevated point sources. For the model studies reported in this document, the value of u^* was obtained from

$$u^* = u_1 (h_s/z_1)^{\varepsilon} \quad \text{for } h_s \geq z_1 \,, \qquad (7)$$

where

u_1 = wind speed measured at height z_1,

z_1 = 6.0 meters, which is the height of the standard anemometer at Newark Airport

and ε = 0.2

The plume rise equation is appropriate for the neutral stability condition, but it must be modified for application over a range of stability conditions. The following modification is used to allow for a range of from 1.3 Δh for very unstable conditions to Δh for neutral stability.'

$$h = h_s + \Delta h\ (1.4 - 0.1L).$$

The Holland plume rise equation Eq. (6) frequently underestimates the effective height of emission; thus its use often provides a slight "safety" factor. For some point sources (e.g., power plants with tall stacks), the effective emission height will be above the mixing depth when the mixing depth is low. Based on the assumption that the plume will not disperse downward through the stable layer, these cases are identified and eliminated from consideration by the program. For area sources an average effective height of emission is estimated, and is entered as input data.

2.4 Geometrical Details of the ERT/MARTIK Model

1. Treatment of Area Sources

The treatment of area sources is described here first, so that the geometry defined for the area source case can be used in the point and line cases also. Two types of orientation must be considered in the description of the area source case. These are:

a. Geographic orientation: based upon north-south and east-west directions.

b. Receptor centered wind-oriented system: based on the wind direction categories reported in climatological data records.

The symbols used in the description of the area source case are defined in Table 2.

The downwind concentration χ (o,o,z) at the receptor point (o,o,z) in the wind-oriented coordinate system is given for a point source located at (x,y,H) by the Gifford-Pasquill formula (Eq. 1).

In the case of the an area source, the contribution of each element of area is summed in the integration over area:

$$\chi(o,o,z) = \int_x dx \int_y dy \; \frac{Q_A(x,y,H)}{2\pi \sigma_y \sigma_z u} \exp\left[-1/2 \left(\frac{y}{\sigma_y}\right)^2\right] \cdot \left[\exp\left[-1/2 \left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-1/2 \left(\frac{z+H}{\sigma_z}\right)^2\right]\right] \tag{8}$$

In the present application, a rectangular area source is assumed, with a uniform source distribution Q_A. See Figure 3 for the geometry applicable to this discussion. Eq. (8) becomes:

$$\chi = Q_A \int_{x_1}^{x_2} dx \; \frac{1}{2\pi \sigma_y \sigma_z u} \; F_z(z,H,x) \int_{y_{min}}^{y_{max}} dy \exp\left[-1/2 \left(\frac{y}{\sigma_y}\right)^2\right]$$

where

$$F_z(z,H,x) = \exp\left[-1/2 \left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-1/2 \left(\frac{z+H}{\sigma_z}\right)^2\right] \tag{9}$$

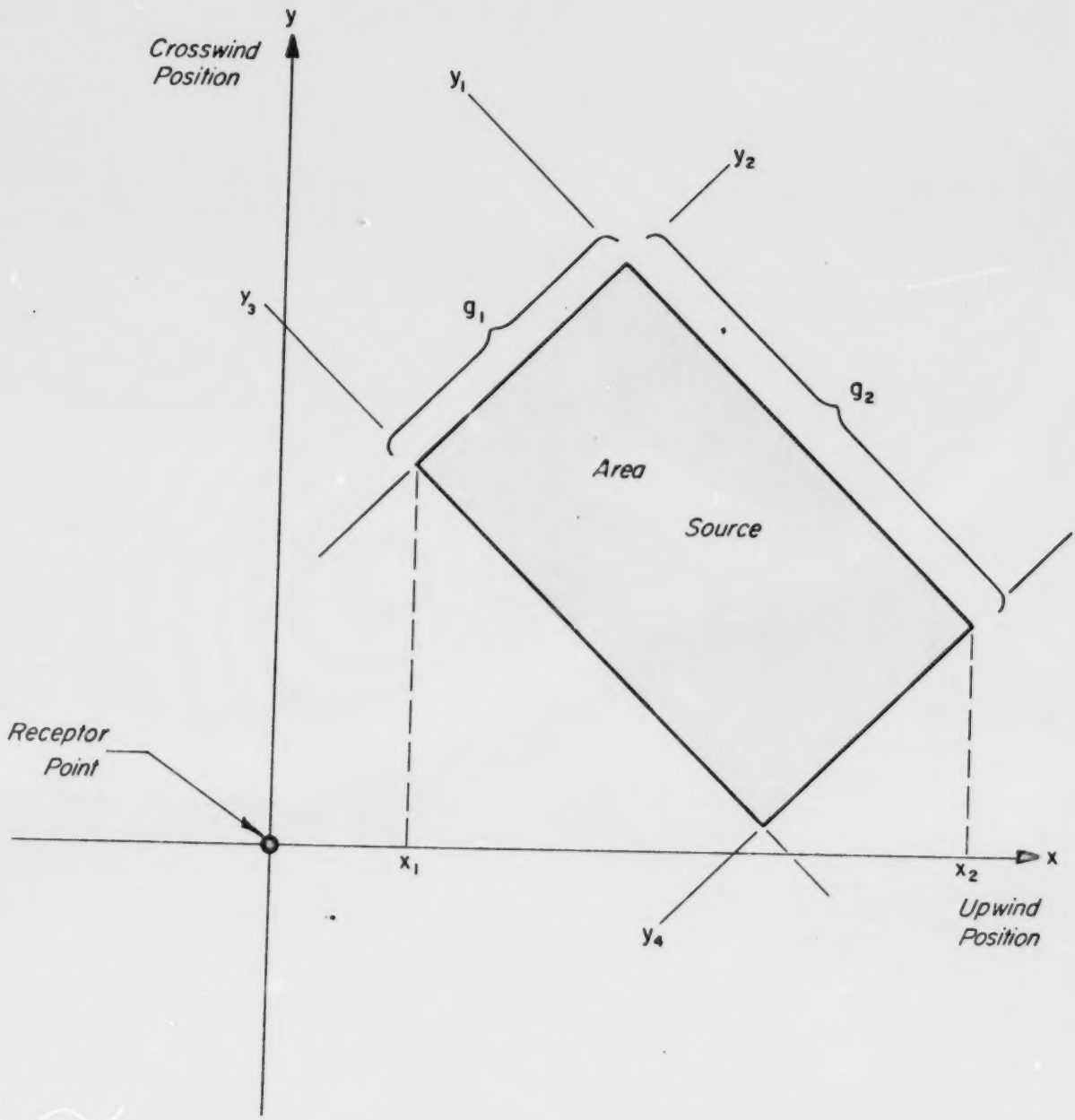
TABLE 2

GLOSSARY OF TERMS FOR AREA SOURCE GEOMETRICAL DESCRIPTION

RH, RV	receptor coordinates in horizontal (east-west) and vertical (north-south)directions, meters (system a)
SH, SV	horizontal and vertical coordinates of the source center, meters (system a)
g_1	dimension of rectangular area source in horizontal (east-west) direction, meters (system a)
g_2	dimensions of source in vertical (north-south) direction, meters (system a)
x	upwind direction and coordinate, meters (system b)
y	cross-wind direction and coordinate, meters (system b)
x_1, x_2	projection of maximum and minimum cell extent upon x-axis, meters (system b)
$y_1 \rightarrow y_4$	parallel lines $y = y(x)$ defining boundaries of cell (system b)
θ	wind source direction angle, measured clockwise from vertical (north) direction, radians
u	wind speed, meters/sec
σ_x, σ_y	variances of plume concentration in x,y direction, meters
c,d	coefficients for determination of σ_z in meters
z	receptor height coordinate, meters
H	source height coordinate, meters
X	integrated concentration due to source distribution in source, $g/meter^3$
q	point source emission rate, g/sec

TABLE 2 Contd

Q_A	source emission density for source (assumed uniform), g/meter^2-sec for area source
V	transfer function: concentration due to unit source distribution (seconds per meter): $\chi = Q \cdot V$
Δx	increment in x for numerical summation along downwind axis, meters
M	number of x increments within source
N	number of x increments in maximum downwind displacement



ure 3 Geometry for Area Source with Dimensions g_1 and g_2 in the Horizontal Plane, Shown in the Receptor-Centered Wind Oriented Coordinate System

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and y_{max} and y_{min}, the crosswind integration limits, are functions of the integration variable x, and represent the intersection of the midpoint of the elemental strip with the geometrical boundary of the area source. Computer realization of Eq. (9) may be efficiently achieved by summation of elemental strips (see Figure 4) from the limits x_1 to x_2. Note that if x_1 is negative, the limits are from 0 to x_2, and that if x_2 is less than or equal to zero, the entire source is downwind of the receptor point, and the integral vanishes.

For numerical evaluation the integration over x in Eq. (9) is replaced by a summation over a total of M discrete intervals from x_1 to x_2. With this substitution Eq. (9) becomes

$$\frac{\chi}{Q_A} = V = \frac{\Delta x}{u} \sum_{i=1}^{M} F_z(z,H,x_i)\ F_y\ (x_i) \tag{10}$$

where

$$F_z = \begin{cases} \dfrac{1}{2\pi\ \sigma_z} \left[\exp\ \left[-1/2\ \left(\dfrac{z-H}{\sigma_z}\right)^2 \right] + \exp\ \left[-1/2\ \left(\dfrac{z+H}{\sigma_z}\right)^2 \right] \right]; & x < x_T \\ \dfrac{1}{D}, & x > 2\ x_T, \end{cases} \tag{10a}$$

F_z is given by a linear interpolation between the two cases above for $x_T \le x \le 2\ x_T$.

D = mixing layer depth

and

x_T = trapping distance, such that $\sigma_z = 0.47$ D.

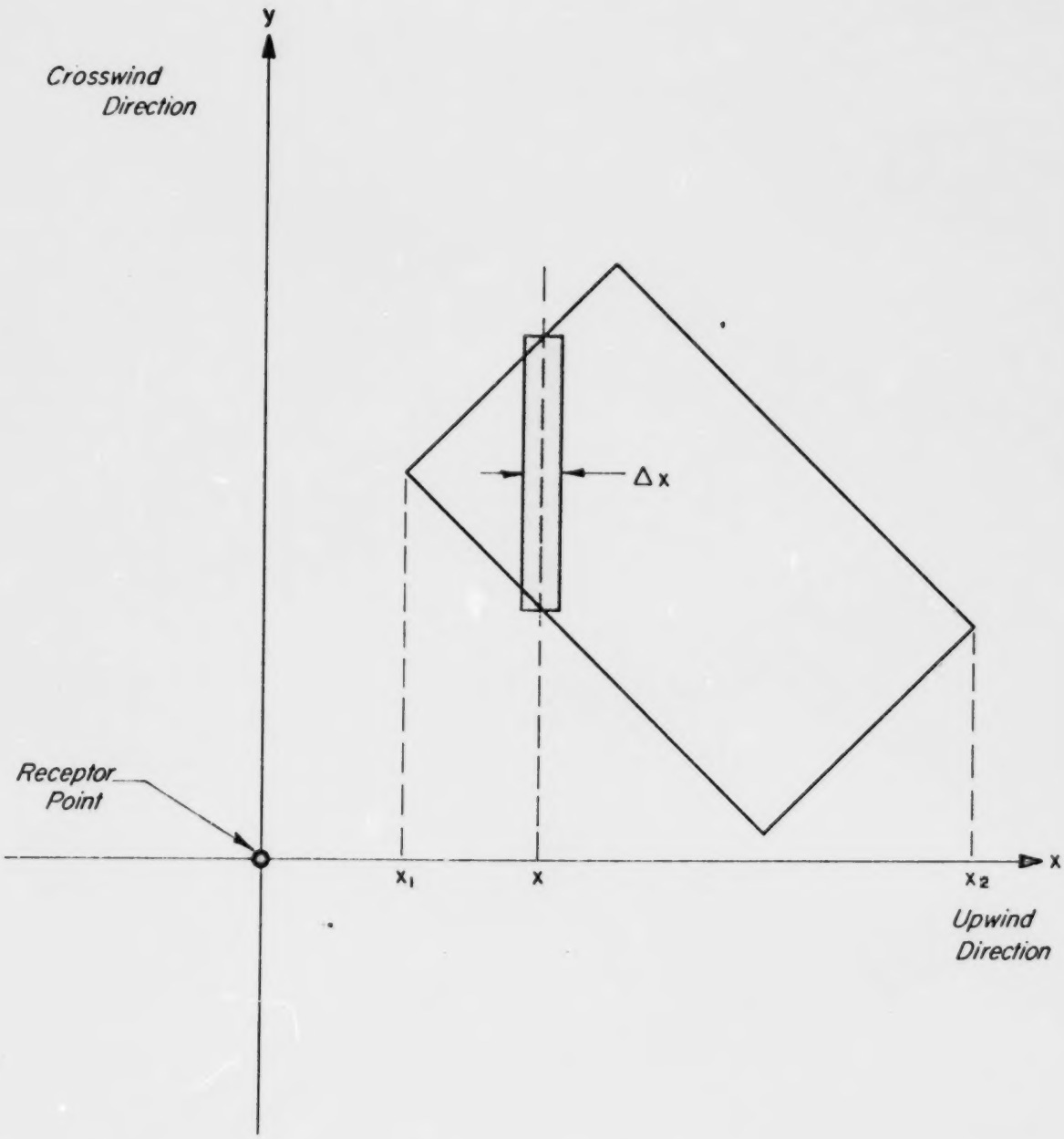

Figure 4 Integration Over Source Cell Area by Summation of Elemental Strips from x_1 to x_2

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In this area source case the y-interpolation function, F_y in Eq. (10), is given by the following integral form (see Figure 5).

$$F_y(x) = \frac{1}{c} \int_{y_{min}}^{y_{max}} \frac{c - |y-y'|}{c} \, dy' \qquad (11)$$

or

$$F_y(x) = \begin{cases} \frac{1}{c} \left| ycf(y_{max}) - ycf(y_{min}) \right|, & (y_{max}, y_{min} \text{ of same sign}) \\ \frac{1}{c} \left| -ycf(y_{max}) + ycf(y_{min}) \right|, & (y_{max}, y_{min} \text{ of opposite sign}) \end{cases}$$

where

$$ycf(y) = \int_0^y \frac{c-y}{c} \, dy = y - \frac{y^2}{2c}, \qquad 0 < y \leq c$$

$$ycf(y) = 1/2, \qquad y > c$$

In order to avoid insignificant computations, several tests are provided in the program to cut off the summation indicated in Eq. (10), or to bypass terms whose contribution lies below a threshold value.

2. Treatment of Point and Line Sources

The concentration $\chi(o,o,z)$ at the receptor point (o,o,z) in the wind-oriented system is given for an elemental point source at x,y,H by the Gifford-Pasquill formula (Eq. 1).

For a line source distribution, the concentration at the point (o,o,z) is thus the integral along the line of elemental strips of length $d\ell$

$$\chi_{line}(o,o,z) = \int_{x_1,y_1}^{x_2,y_2} \frac{d\ell \cdot Q_L(x,y,H)}{2\pi \, \sigma_y \sigma_z \, u} \exp\left[-\frac{1}{2} y^2/\sigma_y^2\right] \qquad (12)$$

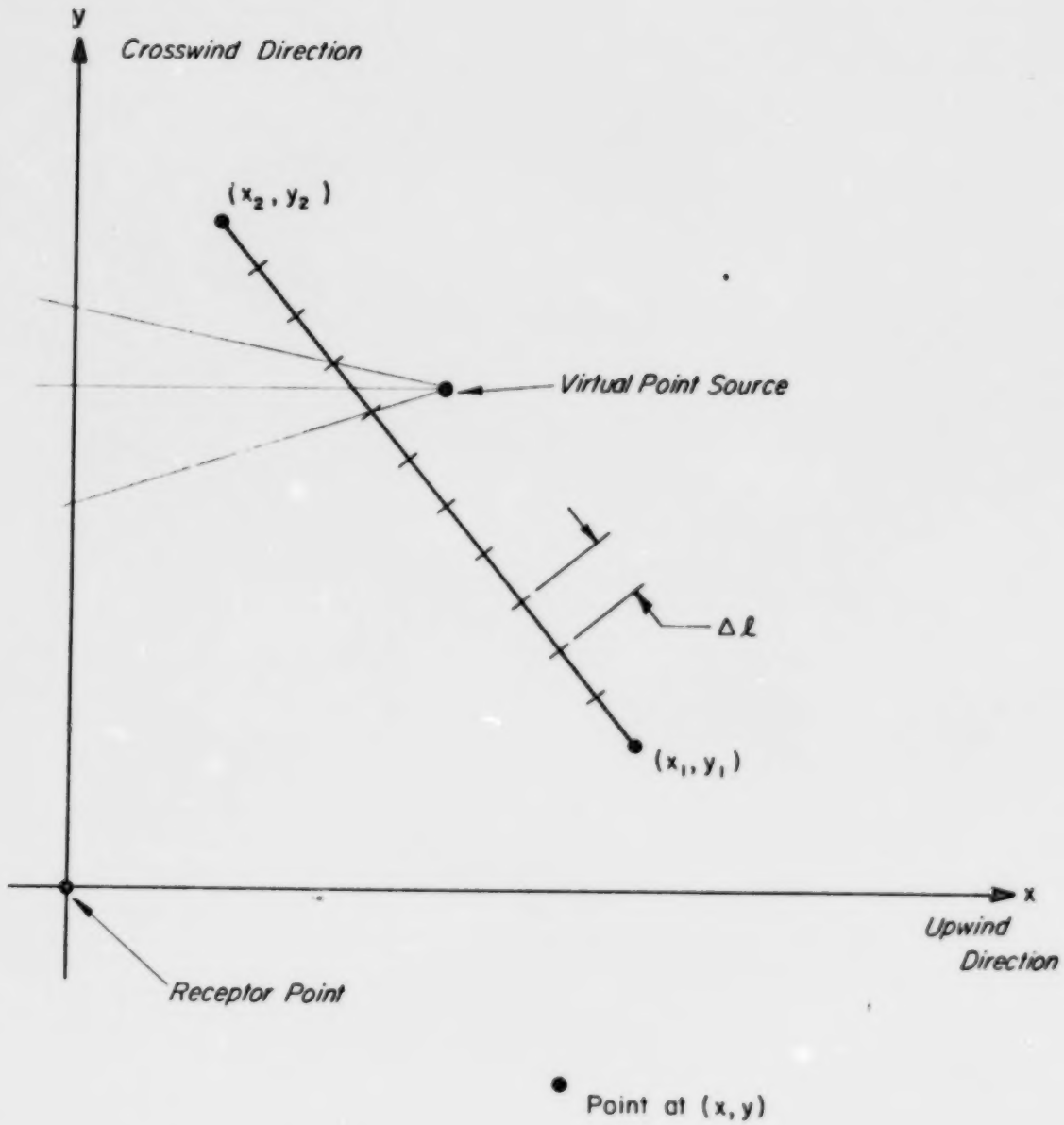

Figure 5 Geometry for Determination of Concentration Due to Point and Line Sources

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$$\cdot \left\{\exp - \frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2 + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

where $Q_L(x,y,H)$ becomes the line source emission density in g /m-sec.

The concentration for constant emission density Q_L may be written as:

$$\chi(o,o,z) = \frac{Q_L}{u} \int_{x_1,y_1}^{x_2,y_2} V(o,o,z;\ x,y,H)\ d\ell \qquad (13)$$

with the transfer function V given for time average calculations by

$$V(o,o,z;\ x,y,H) = F_y(x,y) \quad F_z(x,z,H)$$

where

$$F_y = \frac{c(x) - |y|}{c^2(x)} \qquad (13a)$$

$$c(x) = 0.398 \cdot x$$

with F_2 as given in Eq. (10a).

The numerical integration of Eq. (13) is obtained by representing the line integral as a summation over a set of M virtual points, and displaced upwind by an amount which increases the sector width c by Δy:

$$\underset{\text{line}}{\chi(o,o,z)} = \frac{Q_L}{u}\Delta\ell \sum_{k=1}^{M} V(o,o,z;\ x_k,\ y_k,\ H)$$

The modified sector width c' is then given by

$$c' = 0.398 \cdot x + |\Delta y|.$$

The geometry for determination of $\chi(o,o,z)$ due to a point source at (x,y,H) is shown in Figure 5. For point sources, χ is determined by straightforward solution of Eq. (10a)

$$\chi(o,o,z) = \frac{q}{u} \cdot F_y(x,y,) \; F_z(x,z,H)$$

with q the total source emission rate in grams/sec and F_y and F_z as defined in Eqs. (10a) and (13a).

2.5 Operation of the Model

A detailed description of the operational instructions for the model, including specifications for input data and interfacing with the data output routines, is contained in the User's Manual.

3. DATA USED IN THE MODEL ANALYSES

3.1 Introduction

Three principal types of data are required for any atmospheric dispersion model analysis. These are:

1. Source Data

Emission data for all pollutants of interest must be available. Five pollutants were considered in these model projections: SO_2, CO, nitrogen oxides, particulates, and hydrocarbons. The emission data log may contain a combination of point, line and area sources. Information required for each source includes emission rate, location of the source, and engineering data necessary to determine plume rise.

2. Transport Data

This generally includes meteorological data and information on ground topography in the region of interest. The model requires climatological records indicating the joint frequency of occurrence of wind speed, wind direction, and atmospheric stability classes, appropriate for the model region. The influence of topographic features is generally treated by appropriate modifications to available wind speed and direction data. In the present analysis, data from Newark Airport were judged to be representative of the model region and were used without modification.

3. Concentration Data

Air quality measurement data must be used for validation of the model calculations. If it were possible to model atmospheric transport and dispersion processes with great reliability, it would not be necessary to incorporate ambient atmosphere monitoring data in the model program.

However, current capabilities with models require direct evaluation of model results to actual measurement data. For the present study an array of air quality monitoring data gathered by the New Jersey Department of Health at several locations near the planning region was used as the basis for model validation.

This section of the report serves three purposes: First, the criteria for selection of the appropriate data of each type are identified. Second, the actual choices of data used in the present study are identified. Third, suggestions concerning other possible uses of data to support the modeling effort are summarized. Reasons for rejection of these analyses in the present case are also identified. It is hoped that the discussion of criteria for data selection, and the suggestions for use of alternative data types may be useful to other investigators involved in similar modeling studies dealing with air pollution impact expected in areas under planning or development.

3.2 Meteorological Data

1. The Uses of the Meteorological Data in the Model Study

Three separate uses of meteorological data arise when a modeling project is undertaken. These are:

a. Initial Definition of the Influence Region

The influence region for a study area is defined as the geographical region containing the emission sources responsible for at least 90% of the ground level concentrations (averaged throughout the study area) of all pollutants considered. Emissions data from the entire influence region will be included as input data to model calculations.

The meteorological data required to determine the influence region is either a stability wind rose (expressing the joint frequency of occurrence of wind speed, wind direction and stability class) or a simple wind direction rose. The most important meteorological information entering the determination of the influence region is the frequency of occurrence of each wind direction in the vicinity of the model region.

b. Model Validation

The full set of meteorological data required for model calculations (i.e., a stability wind rose) must be available for the time period used for model validation studies. In the present case validation was carried out for the 1969-1970 period, and the 1970 meteorological data was used as input to these model calculations.

c. Model Projections to Future Times

The desired output from the model calculations are estimates of air quality corresponding to land use patterns expected in 1990. The meteorological data input to the model should represent stationary values, not the record of a single year. In this study a 10-year average record of meteorological data has been used for the projection studies.

2. Criteria for Selection of Meteorological Data

There are three principal criteria for the selection of meteorological data for model use: representativeness, reliability and completeness. A final choice of data will reflect a balance among these three.

a. Representativeness

The ERT/MARTIK model, in common with all gaussian plume dispersion models, normally employs a constant set of meteorological parameters throughout the model region. Therefore the climatological data used in the calculations must be chosen for good representativeness within the region. (It should be noted that there are no wind trajectory data available on a climatological basis which might be used in the calculations. Therefore, if the model were modified to incorporate variable winds and stability within the planning region, there would be no suitable input data for calculations.)

The requirement of representative meteorological data demands that an observing site close to or in the planning region be chosen, and that the site have exposure (relative to local topographical features) which is typical of conditions within the planning region. When topographical features change significantly within the planning region, model sensitivity calculations can be used to estimate the range of error associated with this variability.

b. Reliability

The requirement of reliability in the meteorological data normally favors the choice of records from official National Weather Service observing stations. When data from other sources is considered, the questions of instrument exposure and calibration in the field should be investigated carefully.

c. Completeness

Records from first order National Weather Service stations will normally be complete and available. Since a multiple-year average is required for

model projections, the availability of such an extended record should be investigated before any meteorological data from other sources is used.

In summary, the usual choice of meteorological data will be that of the most representative, long-term record available from a local National Weather Service observing station. Other sources of data may occasionally be chosen because of better representativeness within the model region, but such data must be reviewed carefully for reliability and completeness before it is selected.

3. Data Selected for Use in the Present Study

After a review of several possibilities (discussed in the following section) it was determined that the National Weather Service records for Newark Airport should be used as the meteorological data input in this study. The Newark Airport location is approximately 5 km from the southwestern corner of the Meadowlands planning region.

For determination of the influence region the Newark wind direction rose data for 1956-1965 were examined.

For model validation studies, the stability wind rose data (available as output from the STAR program at the National Climatic Center, Asheville, North Carolina) for the Calendar Year 1970 were employed.

For model projections to 1990, the STAR program climatological data for the 10-year period 1956-1965 were used. This period was selected because the National Weather Service changed its practice at the beginning of 1966. Prior to that time climatological data for each hour was logged at Asheville. Since that time data records have been kept on a three-hourly basis. The 1956-1965 record represents the most recent, 10-year record of hourly observations available for use in the model projections.

4. Other Meteorological Data and Analysis Methods Considered for Use in the Model Studies

Several other sources of data were investigated for possible use in the model studies. The most important are summarized here:

a. Secaucus Data

A limited set of meteorological observations (together with air quality observations) were taken by the U. S. Public Health Service at Secaucus, within the planning region. These data were collected during most of a one-year period, beginning in March 1969. While these data have benefit because of the location of the observations, they were not selected for use because of the lack of: (1) a complete annual record; (2) a long enough record for the 1990 projections; and (3) information on calibration and maintenance of the equipment.

b. New Jersey Air Monitoring System Data

New Jersey has been operating wind equipment as part of its air monitoring system at sites in Newark and Bayonne. These data were not selected, because of the greater reliability of the Newark Airport data.

c. Teterboro Airport Data

Teterboro Airport is at the northern edge of the planning region. However, it was decided that the more complete record at Newark Airport was a better choice.

d. Other National Weather Service Stations in New York and New Jersey

The possibility of using data from a more extensive array of National Weather Service stations was considered. However, it was decided that, to

favor procedures readily applicable to other regions, it would be better to use the single record from the station at Newark Airport.

In addition to the other sources of data described here, the possibility of alternative analysis techniques was considered. These techniques included:

(1) Use of an average stability wind rose from two or more National Weather Service stations.

The use of such average data would favor a better representation of the entire model region, and would reduce the possible impact of unusual instrument exposures at a single site. However, it was decided that it is preferable to favor standard procedures, and therefore to adopt the data record from the single, most representative station (Newark).

(2) Use of actual mixing layer distributions from JFK upper level data or from the Environmental Meteorological Support Unit (EMSU) station at LaGuardia Airport. Standard upper level data are taken at JFK Airport, and twice daily vertical soundings have been initiated at the EMSU at LaGuardia Airport. These data would be more representative of actual vertical mixing conditions in the greater New York City area than the standard distributions of mixing depth adopted in the MARTIK model. However, for the present study these data were not used because: (a) It would be very expensive to compute an appropriate data set from a long-term record.

(b) The model does not treat the relationship between emission rate and meteorological variables (except for the basic seasonal differences in emission rates) and this limitation makes it unrealistic to attempt greater accuracy in the treatment of mixing depth.

(3) Use of "typical" mesoscale wind trajectories in the planning region.

There are no standard approaches available at this time which would permit the use of wind trajectory patterns, instead of constant wind estimates. Future model studies may incorporate such standard trajectories, but this is a development area at the present time.

In summary, a large number of "nonstandard" meteorological data sources and analysis techniques were considered for use in the model program. All were rejected in the present case, in favor of a standard technique, suited to the limitations of the model, which can be applied readily in similar studies for other regions.

Two ad-hoc modifications to the meteorological data were considered during the model validation studies. These were (1) the use of lower wind speeds to represent additional frictional drag in built-up areas; and (2) the use of larger nighttime mixing depths, reflecting the urban heat island effect. These are discussed in the model validation section.

3.3 Emission Data

This section discusses the criteria for selection of emission data used in the model, but not the methodology for development of the emission estimates. The general description of the development of the emission data base is contained in the Task 1 report.

1. Criteria for Selection of Emission Data

Five separate criteria for the selection of emission data to be used in the model calculations are discussed here. The final choice of a data set will reflect a balance among these criteria.

a. Accuracy

Generally the accuracy of the emission data should be related to the accuracy desired in the air quality projections. The accuracy of the model results is usually no greater than that of the input data.

However, there are three other considerations which determine the accuracy requirements. First, because of the uncertainties in other elements of the model calculations, there is no benefit resulting from improved accuracy in the emission data, beyond that which matches the accuracy of the remainder of the model elements. In the present case (calculations of seasonal and annual concentration levels in a region with total linear dimensions of several kilometers) it is not useful to develop area source emission data for cell sizes of less than one kilometer in linear dimension.

In the case of point sources, all sources of smaller size (for example, having emission rates of less than 100 tons of pollutant per year) will have no significant influence upon the long time average model calculations, except in the case of sources which are near (within 1000 meters) specific receptor points.

Second, the accuracy of any set of emission data is controlled by the reliability of the basic engineering and planning data. In most cases the specification of accuracy for the emission estimates is in fact determined by the availability and accuracy of the basic data.

Third, more detailed emission data should be prepared, when possible, for the region near the central planning area. Because nearby sources always account for a major part of the average concentrations observed at a single site, it is useful to treat the near-field emission data with optimum accuracy.

b. Completeness

The diffusion model requires a complete set of emission data in the model region. Therefore the emission data base must include estimates for all defined locations. Because the basic planning and engineering data may not be complete, a method for estimating missing data, for substituting "default parameters" for missing information, must be available.

c. Consistency

When emission data is gathered for a large region, the estimates are frequently based on a variety of sources. These may include direct measurements, fuel use data, process output data, materials balance calcu-

lations, heating demands, population density, and others. It is important that data from such widely varied sources be examined carefully for internal consistency, so that local anomalies in the estimated emission patterns do not result from the variability in this initial data analysis step.

d. Geometry and Resolution of the Sources

The ERT/MARTIK model is capable of treating, at the same time, a general array of point and line sources, and rectangular area sources of any dimension. The basic question to be resolved in the choices among these source geometries is "How many sources should be treated as specific point and line sources, and how many should be aggregated with the general area source data?"

For calculation of annual average concentration patterns the following guidelines may aid in the choice of the number of point and line sources selected for direct representation in the model calculations.

- For a single model area the total number of point and line sources treated individually will normally be of the order of 100 (i.e., between 50 and 200). If more than 200 sources are treated individually in the model, computation time becomes large, with little benefit in improved model accuracy. (The basic accuracy limitations of the model prevent useful resolution of larger numbers of individual sources.)

- It is useful to treat point and line sources in greater detail in the central planning region, where the most accurate concentration estimates are desired.

- Smaller sized area sources are also recommended for use in the central area.

e. Geographical Coverage

Ideally, emission data to be used in a model calculation should be available for the entire area which contributes significantly to the observed or estimated concentrations. (When such data are not available, the model must permit treatment of "background" concentrations, arising from areas not included in the model calculation.) The definition and evaluation of an "influence region" for emissions data is described in the following subsection.

2. Estimation of the Emissions Influence Region

The air pollution concentration observed at a point for a specific time period is composed of contributions from all nearby upwind sources. Sources nearest the receptor point will have a much stronger effect than those further upwind because of wind direction variations in time, dilution by horizontal and vertical turbulent mixing, and because of possible removal and transformation processes. Therefore, for uniform accuracy of estimate of the concentration field, the distribution of sources near the receptor must be treated in more detail than the distribution further away.

For efficiency in the determination of an emission inventory, for use in regional modeling, it is necessary to estimate the extent of the surrounding area which includes the significant sources of emission affecting the receptor concentrations. The influence region is generally related to the local meteorology (for example, skewed toward the prevailing wind direction), the regional distribution of source strengths, and the pollutant removal

or transformation rates. In order to form a practical measure of the influence region, the region must be defined as that from which some high percentage (less than 100%) of the observed concentrations arise. In this study the influence region is defined as the 90% contribution area.

The influence region must be determined separately for each wind direction sector defined in this study by the upwind $22\text{-}1/2^{o}$ wedge-shaped area whose emissions can contribute to the concentration at the receptor. Observed values of the wind direction are expected to be representative of the average only over a mesoscale range of up to perhaps 100 km. They would not be expected to be representative of the average over a synoptic scale of the order of several-hundred kilometers.

For a continuous distribution of emission density in the upwind sector, the concentration at the receptor can be expressed as a function of the influence radius, R, as

$$\chi(R) = \int_{o}^{R} \int_{-\pi/16}^{\pi/16} Q(r,\theta) \cdot V(r,\theta) \cdot T(r)\ r d\theta dr \qquad (14)$$

where

$Q(r,\theta)$ is emission rate density $(g/m^2 sec)$

$V(r,\theta)$ is the transfer function relating the mean transport velocity and source strength parameters

and

$T(r)$ is a decay term related to the source-receptor travel time, but expressible as a function of distance for a given transport velocity. (The decay term is frequently expressed as a exponential which decreases with increasing time).

Since $Q(r,\theta)$ is not known at the beginning, the equations cannot be solved directly, and it is necessary either to solve for the influence region boundary iteratively, or to use equation (14) as a qualitative guideline for evaluating the boundary. One approach which permits considerable insight into the problem of influence region definition is discussed here. If we begin with an approximation of the near-field emissions (i.e., those within the first few kilometers) in the vicinity of the Meadowlands, we can calculate the approximate contribution to the total concentration from these sources. Then we can consider the influence from more distant sources, by assuming (with uniform mixing and no decay) that these sources will add in inverse proportion to their distance from the Meadowlands. At larger distances (for example, greater than 50 kilometers) the effects of decay or removal processes will become important, and will cause the impact of contributions to fall off even more rapidly. A distance scaling system can be developed to incorporate these cases and, for the Meadowlands region, it is possible to make a reasonably good evaluation of the 90% emissions influence region. We have concluded that, for the planning region itself, over 90% of the expected concentrations arise from within the 17-county interstate planning region, including the counties in Connecticut. The only possible important influence from outside this region is the greater Philadelphia area, which might contribute several percent to the background concentrations observed in the planning region. Because any contribution arising from the Philadelphia area would have a nearly uniform effect throughout the planning region, it was decided that this contribution would be treated adequately by the model validation, and that the incorporation of a Philadelphia source in the model calculations would not improve the accuracy or representativeness of the results.

3. Emission Data Selected for Use in the Present Study

The emission data selected for use in the model study is defined according to four geographical zones. These zones are defined as:

Zone 1: Meadowlands plan boundary

Zone 2: Outside of Zone 1 to approximately 1 mile beyond the Meadowlands plan boundary; defined by town lines except to the south (Newark and Jersey City, and includes Secaucus).

Zone 3: Outside of Zone 2 to approximately 5 miles beyond the Meadowlands plan boundary; defined by town lines; includes Manhattan in the New York part of the region.

Zone 4: Remaining New Jersey and New York counties in the Abatement Region (1955/1966).

Other: Connecticut counties in the New York - New Jersey-Connecticut Abatement Region.

Figure 6 Illustrates these four zones.

The selection rules for point sources in the model are:

Zone 1: All sources with rates greater than 100 tons/year (for any one single pollutant); all stacks considered to be separate point sources; where stacks have exactly the same parameters, a stack multiplier notation is used.

Zone 2: Same as Zone 1, except all stacks at each source are aggregated into one (or, more if more than one predominant set of stack parameters exist) source using the major stack parameters.

Figure 6 The Four Geographical Zones Used in the Development of the Emission Inventory

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Zone 3: Same as Zone 2, except much of the data are estimated according to fuel use, process output and other parameters.

Zone 3: Manhattan - Same, except for cutoff at 500 tons/year The area sources for Manhattan have greater emissions than other areas; therefore, 100 tons/year is less significant as a point source.

Zone 4a: Remainder of Bergen, Passaic, Essex, and Union counties- Same except for 500 tons/year cutoff.

Zone 4: Remainder of 17 county region - Same except for 1000 tons/year.

Other: Connecticut counties in 1969 area of Air Quality Control Region - Same except for 1000 tons/year.

Line sources were included in the model only for major links, as identified by the New Jersey Department of Transportation. For most of the model case studies, a total of 50 line source elements were included. Line sources were included explicitly only in Zones 1 and 2. In the other regions, all line source data was aggregated into the area source distributions.

The area source data has been organized as follows:

Zones 1 through 3 (and part of Zone 4):

Area cells of 8 x 8 km dimension were used for general calculations. Sensitivity studies, and detailed studies in the vicinity of the Meadowlands region used 1 x 1, 2 x 2 and 4 x 4 kilometer cells.

Zone 4: (The portion which is greater than 8 km from the planning region)

Area cells of 16 x 16 kilometer dimensions were used for general calculations.

Counties in Connecticut:

Area sources were not included. (Only major point sources were included from this region.)

A more detailed discussion of the choice of emission data, and a listing of data used in the model studies, appear in the Task 1 report.

4. Other Emission Data Considered for Use in the Model Study

Two other types of emission data were considered for possible use in the model study. These are:

a. Sources Near Receptors

In order to investigate the importance of sources very near the measurement sites (i.e., within the first several hundred meters), a number of special calculations were performed, incorporating near-field sources. These investigations were directed in particular toward the question of the influence of adjacent roads on the measurements of CO, NO_X and hydrocarbons. It was decided that, for the long time average cases being considered, it was not necessary (nor possible) to incorporate the influence of emissions from adjacent, medium-duty roads.

b. Sources Correlated With Meteorological Parameters

Many sources have nonzero correlations with the meteorological parameters treated by the model. For example, winter space heating demand is above average on days with northerly winds. Also, motor vehicle emissions are greater during the daytime, when mixing depths are greater.

Model accuracy would certainly be improved if the joint frequency distribution of meteorological parameters and emissions rates were treated specifically. However, it was considered to be outside the scope of the present work to accumulate the necessary data base, and to make the required model modifications, in order to include this improvement. (However, it should be noted that gross meteorological variability related to winter-summer differences in emission rates was included specifically in the model studies.)

3.4 Air Quality Monitoring Data

1. Criteria for Selection of Air Quality Data

Monitoring data must be used to evaluate and refine the performance of the diffusion model and its input data. In most cases the principal criteria for selection of monitoring data for model validation is availability: the total number of monitoring sites in any single region is usually very limited. The Meadowlands planning region itself does not contain any continuously operated air quality monitoring site. However, there are a large number of monitoring stations, of various types, within 50 miles from the planning region. Also, observations were carried out for a single location within the planning region, in Secaucus, for slightly less than one year in 1969-70.

Several of the criteria for selection of air quality monitoring data are similar to those for the meterological data, and are mentioned only briefly here.

a. Representativeness

The question of representativeness is particularly difficult to evaluate for air quality monitoring data. Mahoney et al (1969), in a study of multiple station SO_2 observations in the Boston region, showed that local variability in concentrations (on a scale of 2 miles or less) is at least as important as variability on a regional scale of several miles, in multiple-source regions. Most monitoring stations are placed in areas where high concentrations are expected, and data from all of these stations will not be representative of the lower concentrations expected in the areas between observing stations.

Because of the small amount of monitoring data available, it is usually not possible to eliminate data from use because of lack of representativeness. Instead, the available data are normally used, with the understanding that they frequently reflect near-maximum concentrations in central urban locations.

b. Reliability

The types of monitoring equipment used for all pollutants except particulates have changed rapidly during the past few years. Only equipment of recent manufacture should be considered of good reliability, particularly for the recording of relatively low level concentrations. Instrument reliability is especially important for the examination of long period average concentrations, because of the possibility of bias errors in the lower concentration ranges.

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c. Length of Record

For the present study a full year's record is necessary for model validation. Longer records are desirable, to permit checking for internal consistency in the data, and to examine for trends corresponding to known (or estimated) emission reductions over the past few years.

2. Data Selected for Use

Data sources evaluated during the present study include the following:

a. The New Jersey continuous air monitoring network, including two major trailer sites (at Newark and Bayonne) near the planning region and other satellite monitoring stations near the region. The general locations of these sites are identified in Figure 7.

b. The New Jersey high-volume sampler network, including a large number of sites in the northern part of the state. Locations of these stations are shown in Figure 8. Observations are made for one day each week at these sites.

c. The 38 station air quality monitoring network operated by New York City.

d. Data obtained at Secaucus by the U. S. Public Health Service between March 1969 and February 1970.

e. Measurements during the summer of 1966 made in support of the New York-New Jersey Interstate Abatement Activity.

f. Other data in southern New York and northern New Jersey available in the National Aerometric Data Bank.

Several types of data from these sources were employed during trial calculations, and were examined extensively during initial validation studies.

Figure 7 New Jersey State Bureau of Air Pollution Control Continuous Air Monitoring Network

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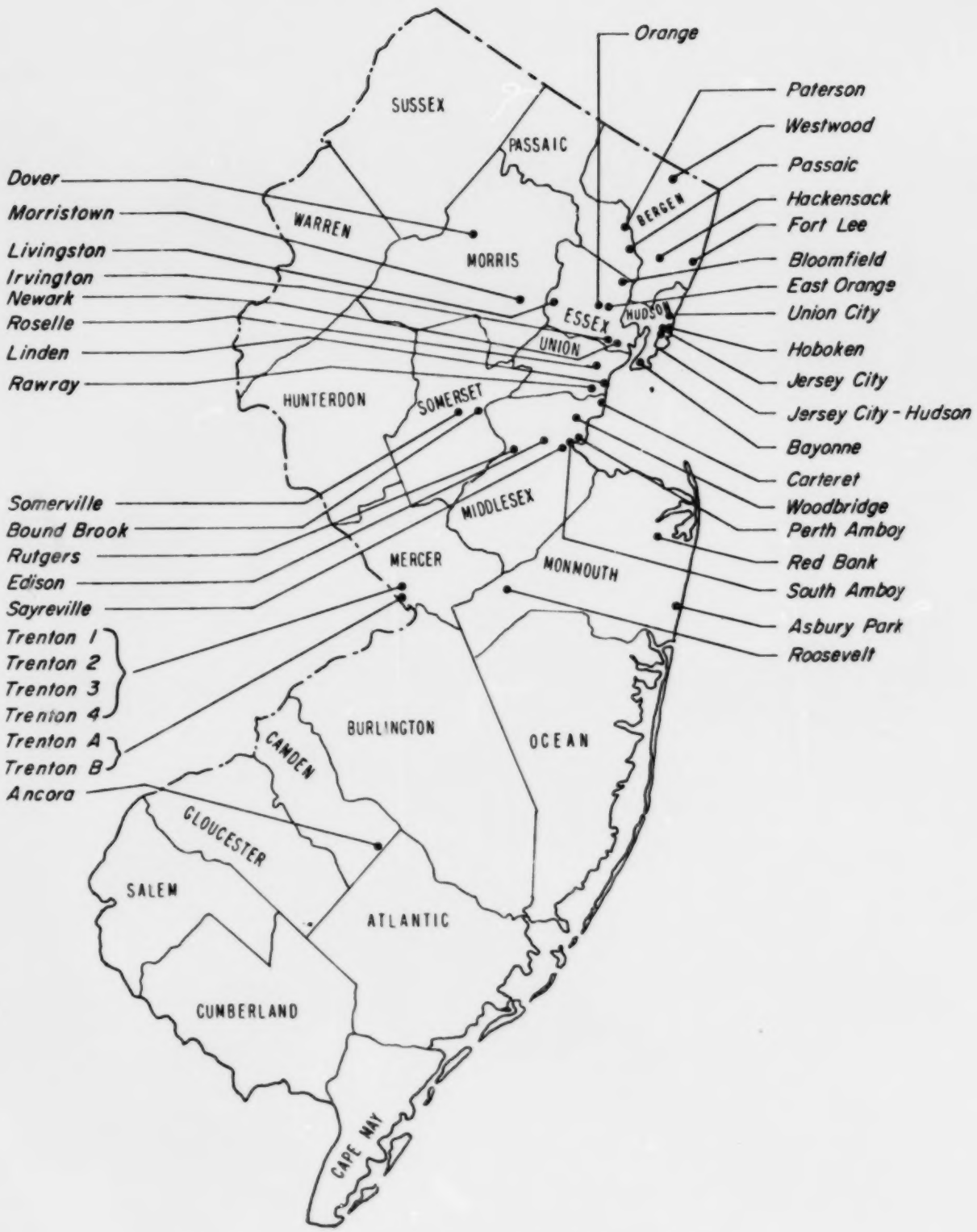

Figure 8 New Jersey High-Volume Sampler Network

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For specific calibration of the model, it was decided to use data only of the same type, (from the New Jersey network) and from locations nearest to the planning region. Therefore, data from five stations in the New Jersey network (Newark, Bayonne, Jersey City, Hackensack and Paterson) were chosen. Model calibration parameters were developed for summer, winter and annual cases from these five locations.

3. Other data considered for Use

Several combinations of the available monitoring data were in fact used during the model validation studies. These are described in the next section, which discusses the model validation procedures.

4. MODEL VALIDATION PROCEDURES AND RESULTS

4.1 Introduction

In this section we discuss the approach adopted to validate the air pollution dispersion model employed for the Hackensack Meadowlands project.

The primary objective of the validation effort was to assure that the model adequately predicted concentration values over the time and space scales of interest and over the range of expected input data values. For purposes of definition, a distinction should be made between "calibrating" a model with observed data and "validating" a model with observed data. The former operation can be as simple as determining "calibration factors" defined as the ratio of observed values to predicted values or determining a least-square regression line relating predicted to observed values. If the calibration factors or regression line slopes have values that are not near unity, or if intercept values imply a negative background pollution level, there is a strong implication that the model is inadequately representing some important phenomena. It is important to note in this regard that good correlation (high positive values of the correlation coefficient) is not necessarily evidence of realistic modeling of phenomena. High correlation can even be obtained when highly variable model results are compared with nearly constant observed values (see Figure 9a) or conversely, when nearly constant model results are compared with highly variable observed values (see Figure 9b).

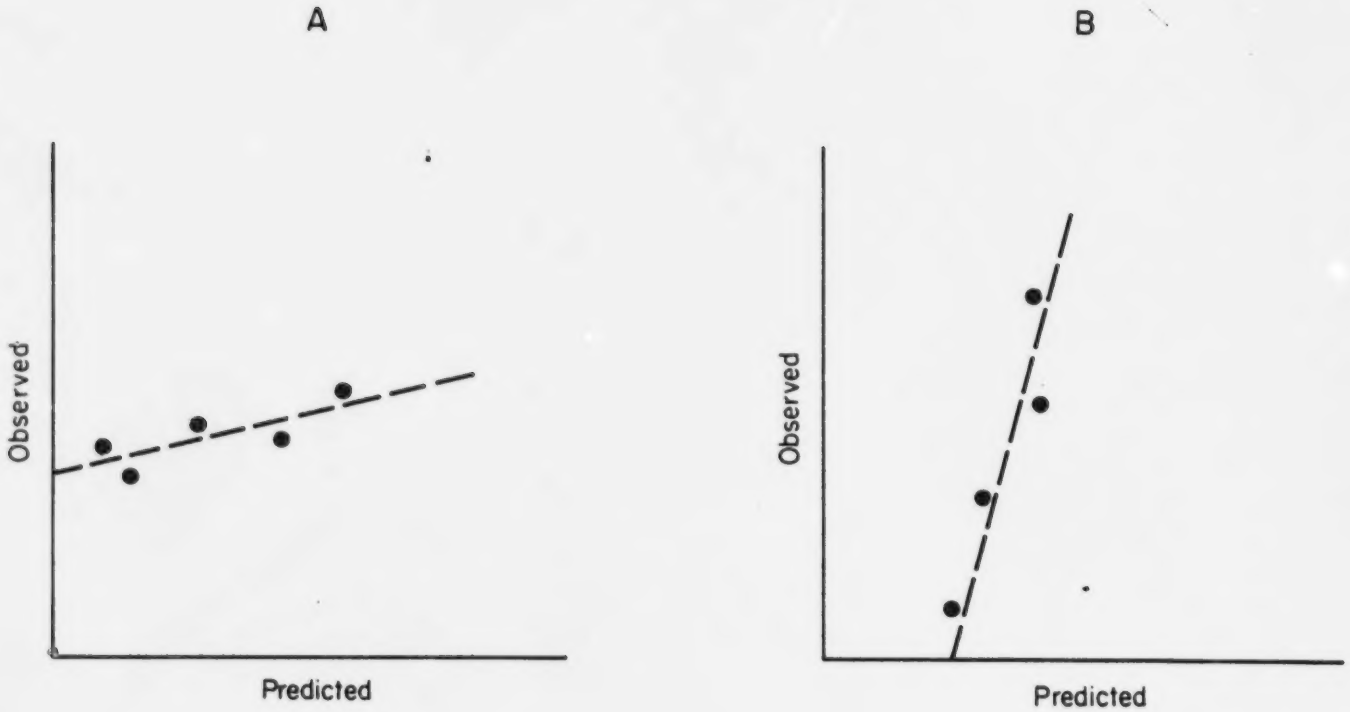

Figure 9 Highly Correlated Regression Line Fits

The judgment of model performance thus needs to include consideration of the intercept values and slope of the least-squares regression line. Positive intercept values should have a physical interpretation as the contribution of "background" levels of air quality associated with emissions from all the other sources not incorporated in the model. Non-unity regression line slope should have a physical interpretation in terms of systematic over or under prediction of some input parameters.

Validating a model implies a detailed investigation of the model results and a comparison of those results with measured values in order to identify and evaluate discrepancies. If the model results compare well with the observed data or if, for the applications to be made, simple correction factors are deemed appropriate, the model may then be simply calibrated with the observed data. On the other hand, if systematic discrepancies are found, the investigation may suggest alterations of model parameters or of the model mechanics which would improve the representativeness of the model. A final calibration is generally required as the last stage of the validation procedure to best adjust for remaining discrepancies between observed and predicted results.

4.2 Procedures for Validating Models

The procedures for validating models will differ somewhat from application to application depending upon the nature and purpose of the study and depending upon the quality of the available data. The validation procedure will normally require a thorough study of the implications of model assumptions and the performance of "sensitivity" studies for various input parameters. The following sections describe the various steps taken to validate the dispersion model developed for the Meadowlands study.

4.2.1 Selection of Data for Purposes of Validation

Because the planning project is concerned with the prediction of air quality levels within and near the Meadowlands for winter, summer, and annual time periods, data for validation was chosen for the same time durations. Model predictions are expected to be most representative in the near region of the Meadowlands, where the source inventories developed are most detailed. For this reason, only data from the five monitoring stations nearest the region were used for validation purposes. (These are the stations at Bayonne, Jersey City, Newark, Paterson and Hackensack). See Figure 10.

The emissions inventory for the validation study was based on estimates for the year 1969. However, among the five stations chosen for validation, only Newark and Bayonne have data for all pollutants of interest for 1969. Measurements of SO_2, CO and particulates are available for most of 1970 and the entire year of 1971 at the other three stations. The trends in average concentration levels from 1969 to 1971 observed at Newark and Bayonne were used to extrapolate the 1971 measurements at the other three stations back to 1969 levels. This procedure permits the use of a much expanded data base in the validation but introduces some additional uncertainty. In the final calibration, because of the additional uncertainty, the calibration factors from Newark and Bayonne were weighted more heavily than those of the other stations. Table 5 includes a summary of the air quality data used.

As previously noted, meteorological data for 1970 were used in the validation studies. The 1970 meteorological data were adopted for use instead of the 1969 data for the following reasons:

1. Because only two stations (Newark and Bayonne) reported concentration measurements in 1969, all of the initial evaluation

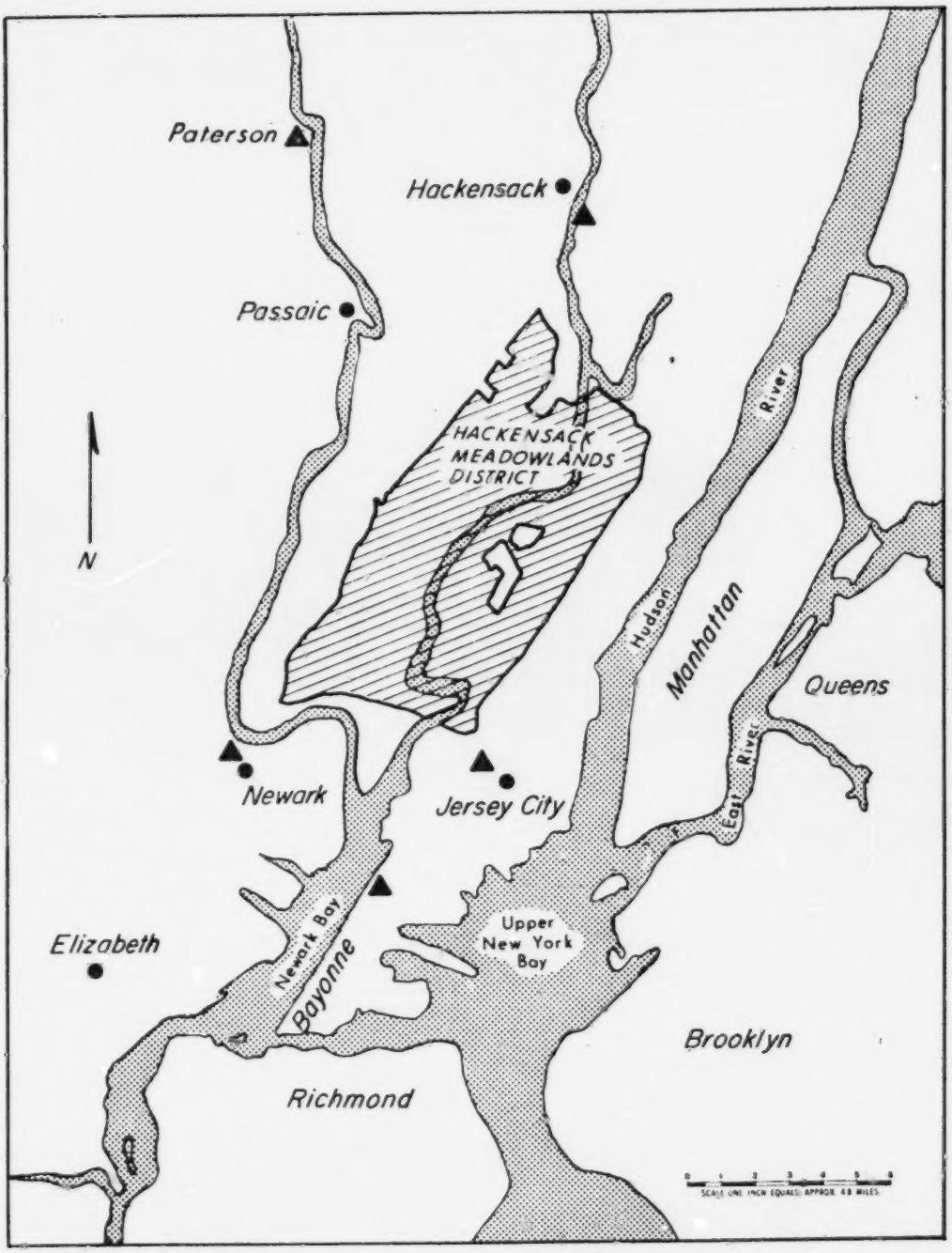

Figure 10 Validation Sites Surrounding the Meadowlands Region

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studies and most of the validation studies involved comparison of model predictions with 1970 air quality measurements, at all five of the stations mentioned above.

2. The year-to-year variability in the seasonal and annual wind rose data at Newark Airport is small compared to the variability in concentrations measurements among the five stations used in the validation studies. Therefore it was preferable to introduce some uncertainity into the meteorological data, in order to incorporate all five stations into the validation procedure.
3. Although the measured concentration data for Jersey City, Paterson and Hackensack were extrapolated back to 1969, these values are directly representative of meteorological conditions in 1970 and 1971.

It should be enphasized that, whenever data from an adequate network of air quality monitoring stations are available for the time period of the emission inventory, the meteorological data from the same time period should be used. The use of differing time basis was required in this case only because of the lack of sufficient air quality measurement data for 1969.

4.2.2 Preliminary Runs to Assess the Initial Agreement Between Predicted and Observed Values

Computer runs were made using the point and line source inventories and a crude area source inventory to make an initial comparison of the values predicted by the MARTIK model with observed data. The inventory included 192 point sources, 50 line sources and 35 area sources. The Newark wind rose and the standard Pasquill-Gifford-Turner stability class dispersion-

rate relations were used. These tests indicated that the model generally overpredicted concentration values of SO_2 and NO_x. It predicted spatially averaged concentrations of CO and hydrocarbons well, but the individual data points did not correlate well with the observed values. Predictions of particulate levels were in good agreement with the observed averages.

4.2.3 Sensitivity Analyses and Identification of Possible Model Improvements

A number of model mechanisms which could account for discrepancies between the calculated and observed values were investigated. These mechanisms are listed and discussed here. Sensitivity tests were made to investigate the effect of some of the model modifications above on the receptor points chosen for validation. Results for these are also presented below.

1. Inclusion of Pollutant Half Lives

The gross effects of removal processes for gaseous pollutants can be simulated by the inclusion of an exponential time decay term in any one of Equations 2,3, or 4. The effect of incorporating a half-life of concentration values to simulate removal processes was investigated specifically for the SO_2 emissions. Test runs were made with a three-hour half-life and with a one-hour half-life. The three-hour half-life caused a 47% reduction of the calculated values while the one-hour half-life caused an 85% reduction.

2. Refinement of Area Source Grid and Inclusion of Nearby Roadways

Minor sources in the immediate vicinity of the sampling locations will have a strong influence on the sampling locations. In order to improve the representation, the area source grid was refined into smaller source grids in the neighborhood of the receptors and roadways adjacent to the receptors were included as line sources.

Nine 16-km area source cells in the neighborhood of the Meadowlands were subdivided into 36 8-km squares and new emission rates were calculated for the new cells. The average levels of concentration were not changed by this alteration, but correlation between observed and computed was somewhat improved. Further refinement of the area source inventory was not thought to be justified using the county-based emission data on area-type emissions.

The effect of adding short line-source segments in the near field of the receptors at Bayonne, Jersey City and Newark was investigated to represent the effect on concentrations of small but nearby roadways. The local contributions increased the concentrations by a maximum of 5%. As a result of this relatively small influence and the inability to predict the level of detail for the year 1990, it was decided not to incorporate the additional roadways into the final emission inventory.

3. Incorporation of the Effects of Correlation Between Diurnal Meteorological Variations and Pollutant Emission Rates

Emission rates of transportation and industrial related pollutants are lower during nighttime hours. Because the atmosphere is on the average

more stable at night, models which do not include diurnal variations in source strength tend to overpredict seasonal and annual average pollutant levels. The effect of diurnal variations in source strength combined with a systematic association of stable atmospheric conditions with nighttime was investigated by postulating a difference between day and night emission rates and analyzing the concentration contributions by stability class. By definition, occurrences of stability class 5 are only associated with nighttime conditions.

The frequency of occurrence of stability class 4 includes the wind speed and direction statistics of the remaining nights. If we assume that the nighttime hours are one half of all hours, and that the nighttime emission rate is A times the daytime rate, where A is expected to be $0 < A < 1$, an estimate of the effects of the diurnal variation of emission rate on long-term averaged concentrations is given by

$$\chi' = \chi \cdot \frac{2}{A+1} (f_1 + f_2 + f_3 + (r_D + r_N \cdot A)\, f_4 + A \cdot f_5) \qquad (15)$$

where

χ is the concentration calculated assuming that there is no diurnal variability

f_i are the frequencies of occurrence of stability class i

and

r_D and r_N are the fractional times of day and night occurrence in stability class 4.

Values of f_i, r_D and r_N for winter, summer and annual time periods are given below in Table 3.

TABLE 3

VALUES OF f_i, r_D and r_N FOR WINTER, SUMMER AND ANNUAL TIME PERIODS

Season	$f_1 + f_2 + f_3$	f_4	f_5	r_D	r_N
Winter	.041	.703	.256	.655	.345
Summer	.243	.489	.268	.525	.475
Annual	.130	.617	.253	.600	.400

Values of χ were computed for values of A between 0 and 1 for SO_2 and CO and the results compared with the measured values. Although overall reductions of computed values could be as large as 40%, no improvement of correlation between observed and computed was found. For this reason and because of the uncertainty in assigning values to A a decision was made to not include this correction mechanism in the model. Since observed correlation was not altered, a simple scaling in the final calibration seemed to have equal merit in accounting for the diurnal effect.

4. Incorporation of Effects of Correlation Between Wind Direction and Emission Rates

Winter emission rates associated with space heating are expected to be positively correlated with the cooler northerly winds. Neglect of this mechanism causes models to overpredict space heating related pollutant levels. On the basis of the insensitivity of the model correlation results to the diurnal variability and recognizing the inability to specify the relation between wind direction and emission rates, this effect was not formally investigated and was left to be corrected by the final calibration.

5. Modification of Dispersive Spread Statistics

Because of reduced evaporative cooling and increased capture of incoming solar radiation in urbanized areas, thermal convection from the ground is more vigorous than in rural areas. In addition, because of their built-up nature, urban areas are aerodynamically rougher than rural areas. These two factors cause enhanced mixing of pollutants and increased plume dispersion spread rates. Unfortunately, data on dispersion rates in urban areas are not as extensive for rural areas. The study by McElroy and Pooler (1968) in St. Louis provides some measures of the increased dispersion rate expected. The table below compares the McElroy-Pooler vertical dispersion coefficients after Koch and Thayer (1971) with the Pasquill-Gifford-Turner values.

TABLE 4

VERTICAL SPREAD STATISTIC CONSTANTS ($\sigma_z = kx^d$)

Stability Class (L)	Pasquill-Gifford-Turner		McElroy-Pooler	
	k	d	k	d
1	.022	1.44	-	-
2	.064	1.12	.072	1.22
3	.150	.860	.169	1.01
4	.270	.680	1.07	.682
5	.372	.580	1.01	.554

The net effect on ground-level concentrations of utilizing the McElroy-Pooler coefficients depends upon the mixing depth and the height of the source emissions. For stability classes 4 and 5 and for low-level area and line source emissions, the McElroy-Pooler σ_z values will cause concentration contributions in the near field to be nearly 1/3 the values obtained using

the Pasquill-Gifford-Turner values. On the other hand, for upper-level sources, ground level contributions will increase because of the increased vertical mixing rate. At some distance downwind (of the order of 10 km for the prevailing meteorological conditions), material is expected to be mixed nearly uniformly from ground-level to the top of the mixing layer. Beyond that distance the choice of the vertical spread rate statistic does not alter concentrations. The net effect on total concentration will therefore depend strongly on the spatial distribution of the sources. A comparison of runs made with both sets of dispersion coefficients for annual cases showed that the net result of utilizing the McElroy-Pooler coefficients was to reduce the average predicted concentration for the five validation receptors by about 40% for SO_2 emissions and by about 30% for CO emissions.

6. Modification of Assumed Mixing Depths

For the same reasons as in item 5 above, the mean mixing depth for urban areas is expected to be larger than that assumed for rural areas. The difference is expected to be largest and to influence ground-level concentration the most under nominally stable atmospheric conditions.

Sensitivity test runs were made for assumed mixing depths of 100, 200 and 300 meters for stability Class 5. Changing the average mixing depth associated with the most stable stability class, from 100 to 200 meters reduced concentrations at the five receptors on the average by about 7%. This relatively low sensitivity is caused by the fact that major sources contributing to the concentrations are in the near field of the receptor and within the distance that the finite mixing depths act as a lid to vertical diffusion of pollutants. Increasing the height from 200 to 300 had hardly any effect on the five receptors.

7. Modification of Airport Velocity Measurements

Several possible modifications to the airport wind speed measurements were investigated and are discussed below:

a. The low level measurements of wind velocity at Newark airport are on the average lower than wind speeds existing at higher levels. This will have two (partially compensating) effects on ground-level concentrations.

The use of the surface level winds in the plume rise equations for stack emissions causes an overestimate of plume rise and thus contributes to an underestimate of ground-level contributions. On the other hand, the use of the low-level wind speed underestimates the average transport rate for pollutants from elevated sources and thus contributes to an overestimate of ground-level concentrations. Concentrations resulting from low-level emissions from area sources or roadway line sources are not expected to be altered significantly by the variation of wind speed with height.

To improve the model representation of these phenomena, power law increases of velocity with height were postulated. The velocity calculated for use in the computation of plume rise was

$$u = u_1 (z/z_1)^{\varepsilon} \qquad (16)$$

where

u_1 was the value measured at the anemometer height z_1,

and the exponent ε is a function of stability class.

Velocities for use in the computation of a "ventilation" velocity were calculated from the equation

$$u = u_1 \frac{(h/z_1)^{\varepsilon}}{1+\varepsilon} \qquad (17)$$

where

h is the effective stack height.

This formula estimates the mean velocity averaged from ground level to the plume height.

b. The wind speed frequency records classify the lowest speed cases (calm) as values between 0 and 3 knots. The average wind speed which really occurs during "calm" conditions (velocities too low to be reliably read by the anemometer) is likely to be skewed toward the 3-knot limit. Instead of utilizing the average of the windspeed class limits (i.e., 1.5 knots) to characterize the wind speed of this lowest class we chose the slightly higher value of 1.75 knots or .89 m sec^{-1}. The net effect on long-term average concentrations is quite small because of the small difference and the small portion of the time that calm conditions are observed.

c. The possibility of simulating an effect of the increased "roughness" of urban areas by reducing wind speeds in the lower boundary layer was considered. Because the model was tending to generally over-predict, and because this type of modification would cause the model to overpredict even further, it was not investigated in specific detail. We note that the incorporation of the power law variation of velocity with height in the calculation of a ventilation velocity does cause the average velocity for low level emissions to be lower than the velocity at emission height by the factor of $1/(1+\varepsilon)$.

4.2.4 Modifications Made to the Model and the Final Calibration Model Results

There were three fundamental criteria used to determine which modifications or parameter changes actually to incorporate.

1. Modifications or parameter changes must be physically realistic which requires that parameters chosen must be within the range of experimentally measured values.

2. Modifications or parameter changes must be appropriate for use in the planning year 1990. This criterion restricted the incorporation of emission rate dependent modifications such as items 2, 3 or 4 in Section 4.2.3.

3. The evaluation of modifications or parameter changes must be based primarily on their effect on the regionally averaged agreement of calculated vs. observed values, rather than on agreement for individual stations. We expect that measurements at the individual monitoring stations will be strongly dependent upon the fine details of the location and operating modes of the nearest (though perhaps small) sources. Because of the nature of the applications of the dispersion model in this study, it is more important that the model predict concentrations accurately over a regional scale rather than accurately predict concentrations at specific monitoring sites. By averaging measured values at a number of sites within a region, the effect of local sources will be minimized, so that a meaningful regional average can be formed.

On the basis of these criteria, only changes in the meterological parameters were finally adopted in the model. The emission rate dependent modifications were not appropriate for the seasonal and annual average calculations, and their effects were left to be corrected by the final calibration.

Sensitivity analyses performed on the meteorological parameters were studied from the points of view of seasonal variations, differences of influence of near and far sources, and effects on dispersions from low and high level sources. The final decisions on specific changes to be implemented were based on our best judgment of the results of the sensitivity tests and experience in other model studies. We were purposefully conservative in incorporating model changes. The modifications made are listed here:

1. A half-life of 3 hours was assigned to SO_2 emissions. An established procedure for simulating removal processes in large-scale dispersion studies does not exist. The problem is complicated by the dependence of removal processes on precipitation, atmospheric interactions with other pollutants, and reactions with buildings and other surfaces. To simulate average effects of removal processes for SO_2 a three-hour half-life is a reasonable number.

2. Vertical spread statistics were adopted from the McElroy-Pooler study in St. Louis. These values better simulate the increased turbulance expected in urbanized areas.

3. Velocities for use in the computation of plume rise were computed from Eq. (16) using the Newark Airport anemometer height of $z_1 = 6$ meters and $\varepsilon = 0.2$. Velocities for use in the computation of a ventilation velocity were calculated using Eq. (17) with the same values of z_1 and ε.

The value of $\varepsilon = 2$ was chosen for purposes of validation as a value representative of the most commonly occurring stability classes 4 and 5.

The value of .89 m sec^{-1} was chosen as representative of the wind speed in the lowest wind speed class and incorporated into the final model validation runs.

4.2.5 Final Calibration of the Model

With the parameter modifications implemented in the model, final validation runs were made for the five receptors for the winter, summer and annual cases. The results were then compared with the observed or extrapolated-observed air quality data for 1969. Table 5 summarizes the observed and predicted data. The ratio of the predicted to "observed" was then calculated for each station, for each season, and for each pollutant for which data was measured. For the sites used in the validation, we recommend the use of these ratios as simple calibration factors. For estimation of concentrations at any other location and, specifically, in the planning region, an average of the calibration factors for the entire region was derived. As noted in Section 4.2.1, the validation air quality data for SO_2 and CO for the Jersey City, Paterson and Hackensack sites was extrapolated backwards to 1969 from the 1971 values. In order to discount this added uncertainty in determining a regional calibration factor, the Bayonne and Newark data were weighted more heavily. The weighting factors were determined simply by requiring that the average of predicted and observed values for Bayonne and Newark sites be weighted equally with the average for the Bayonne, Newark, Jersey City, Paterson and Hackensack sites. Thus, for both predicted and observed values the regional average values for SO_2 and CO were determined by the formula

$$\text{Regional Average} = \frac{1}{2}\left[\frac{V_B + V_N}{2} + \frac{V_B + V_N + V_J + V_P + V_H}{5}\right]$$

TABLE 5

PREDICTED AND OBSERVED VALIDATION DATA

	POLLUTANT	Bayonne		Jersey City		Newark		Paterson		Hackensack	
		Predicted	Observed	Predicted	Observed*	Predicted	Observed	Predicted	Observed*	Predicted	Observed*
WINTER	SO_2 (ppm)	.131	.067	.207	.091	.093	.087	.056	.031	.121	.048
	CO (ppm)	1.96	1.80	2.58	10.7	1.77	4.96	1.59	10.2	2.42	3.40
	HC (ppm)	1.31	2.03	1.07	N. A.	.575	2.17	.520	N. A.	.791	N. A.
	NO_X (ppm)	.257	.097	.362	N. A.	.159	.160	.181	N. A.	.284	N. A.
	**Particulates ($\mu g/m^3$)	132.7	77.6	179.9	112.0	114.0	N. A.	101.5	N. A.	130.1	175.0
SUMMER	SO_2 (ppm)	.041	.042	.090	.032	.024	.033	.021	.018	.033	.012
	CO (ppm)	1.72	.97	4.35	5.6	1.70	3.63	1.74	3.07	2.73	1.27
	HC (ppm)	1.67	1.87	1.42	N. A.	.525	2.50	.529	N. A.	.790	N. A.
	NO_X (ppm)	.137	.083	.296	N. A.	.118	.108	.120	N. A.	.177	N. A.
	**Particulates ($\mu g/m^3$)	72.9	99.4	110.3	106.0	53.2	137.0	63.9	N. A.	64.7	N. A.
ANNUAL	SO_2 (ppm)	.079	.052	.130	.056	.060	.054	.040	.027	.075	.028
	CO (ppm)	2.00	1.28	2.72	7.5	1.94	4.27	1.80	5.9	2.65	2.23
	HC (ppm)	1.46	1.92	1.03	N. A.	.605	2.25	.546	N. A.	.801	N. A.
	NO_X (ppm)	.194	.087	.272	N. A.	.173	.138	.154	N. A.	.228	N. A.
	**Particulates ($\mu g/m^3$)	96.1	92.8	118.9	112.0	84.0	136.1	84.2	82.5	92.7	142.9

*Extrapolated backwards from 1970 and 1971 values to 1969 values (except for particulates).

**Observed values of particulates are 1970 values.

Observed values for Bayonne and Newark are 1969 values.

where V denotes the value under consideration and the subscript, the site location. Table 6 summarizes the calibration factors calculated.

4.3 Discussion

The final calibration factors for the Hackensack region given in Table 6 show that the model underpredicts CO and hydrocarbons, and overpredicts SO_2 and NO_x for all averaging times. Particulates are underpredicted in the summer and in the annual average, but overpredicted in the winter. The overall agreement is thought to be quite satisfactory and well within the accuracy typically found with long averaging-time period projections.

It should be pointed out that although considerable smoothing of data is inherent in both long-time averaged predicted values and observed values, the agreement between predicted and observed values is not necessarily improved by the averaging processes. For example, systematic associations of emission rates with different meteorological conditions will cause systematic disagreements between observed and predicted values over long averaging times. On the other hand, agreement is expected to be better when short-time period observations of air quality (such as over several hours) are compared with model projections using observed values of meteorological conditions (and possibly observed values of emission rates) for input. Thus, when strong diurnal effects on concentration patterns are observed, hourly values are expected to be well correlated with model results which incorporate nighttime and daytime variations in emission rate. Since the model developed in this study is to be used primarily for the longer averaging time applications, it needs to be validated with corresponding long-time averaged data sets.

TABLE 6

RATIOS OF OBSERVED* TO PREDICTED VALUES, BY POLLUTANT AND TIME PERIOD

	Pollutant	Bayonne	Jersey City	Newark	Paterson	Hackensack	Regional Average
Winter	CO	.92	4.00	2.80	6.40	1.40	2.31
	SO_2	.51	.44	.94	.55	.40	.602
	HC	1.56	-	3.78	-	-	2.23
	NO_X	.377	-	1.00	-	-	.616
	Particulates	.585	.62	-	-	1.35	.826
Summer	CO	.56	1.29	2.05	1.77	.465	1.25
	SO_2	1.03	.36	1.38	.86	.363	.875
	HC	1.12	-	4.75	-	-	1.99
	NO_X	.60	-	.92	-	-	.750
	Particulates	1.36	.96	2.6	-	-	1.45
Annual	CO	.64	2.76	2.20	3.28	.84	1.70
	SO_2	.66	.43	.90	.67	.37	.66
	HC	1.31	-	3.72	-	-	2.02
	NO_X	.45	-	.80	-	-	.614
	Particulates	.97	.94	1.62	1.62	1.54	1.19

*"Observed" values for Jersey City, Paterson and Hackensack were extrapolated backward from 1971 measurements to provide estimates for the emission inventory year 1969.

There are several reasons why, for the final calibrations, the determination of a regional-average calibration factor for each pollutant and for each season was most appropriate. These reasons are discussed below.

1. By averaging over the five stations around the Hackensack Meadowlands, errors introduced by the presence or absence of numerous small local emission sources tend to cancel.

2. The number of data points did not warrant a least-squares regression line fit (note that annual values are not independent of the summer and winter values and cannot be used as independent data points).

3. Because the emissions inventory influence region accounts for nearly all of the concentration observed at a point, and since large changes in emission rates are postulated for the year 1990, a forced fit of the calibration lines through zero seemed mandatory; (i.e., a line with a slope equal to the calibration factor and with a zero intercept value.) Only in this way can we be assured that an across-the-board reduction of all emission rates will result in a corresponding reduction of predicted concentrations in the same fraction.

4. The limited amount of data available did not warrant the generation of a spatially varying calibration factor over the region. A regionally varying calibration factor would tend to bias the impact results of alternative land use plans spatially throughout the region. Another level of study effort with more air quality measurements and emission inventory detail would be required in order to determine physical explanations for and confidence in other than a regionally averaged calibration factor.

REFERENCES

Clarke, T. F., 1969: "Nocturnal Urban Boundary Layer over Cincinnati, Ohio." Mon. Wea. Rev. 97, pp. 582-589.

Gifford, F. A., 1961: "Use of Routine Meteorological Observations for Estimating Atmospheric Dispersion, Nuclear Safety, 2(4), pp. 47-51.

Holzworth, G. C., 1964: "Estimates of Mean Maximum Mixing Depths in the Contiguous United States," Mon. Wea. Rev. 92, pp. 235-242.

Koch, R. C., and S. D. Thayer, 1971: Validation and Sensitivity Analysis of the Gaussian Plume Multiple-Source Urban Diffusion Model, GEOMET Report No. EF-60, Rockville, Maryland.

McElroy, T. L., and F. Pooler, 1968: St. Louis Dispersion Study, Vol. II - Analysis, NAPCA Publication No. AP-53.

Mahoney, J. R., W. O. Maddaus and J. C. Goodrich, 1969: "Analysis of Multiple-Station Urban Air Sampling Data," Proc. of Symposium on Multiple-Source Urban Diffusion Models, APCO Publication, No. AP-86.

Martin, D. O. and T. A. Tikvart, 1968: A General Atmospheric Diffusion Model for Estimating the Effects of One or More Sources on Air Quality, presented at the 61st Annual Meeting of the APCA, St. Paul, Minn.

NAPCA, 1969: Air Quality Display Model, National Air Pollution Control Administration, Washington, D. C.

Pasquill, F., 1961: "The Estimation of the Dispersion of Windborne Material," Meteorological Magazine, 90(1063, pp. 33-49.

Turner, D. B., 1969: Workbook of Atmospheric Dispersion Estimates, PHS. publication No. AP-26.

Turner, D. B., 1964: "A Diffusion Model for an Urban Area, J. of Appl. Meteor., 3(83).

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GLOSSARY

Activity, Activity Level - basic land use and transportation planning units of intensity of use - vehicles per day on a highway, acres of residential land use, square feet of industrial plant space.

Activity Index - a numerical conversion factor to transform the level of activity specified for a land use category into demand for fuel for heating purposes.

Air Quality Contour - a contour line in a plane (usually the horizontal or vertical) representing points of equal concentrations for a specified air pollutant.

Air Quality Criteria - factors used in this study that represent a basis for decision-making, for example ambient air quality standards.

Air Quality Prediction - the calculation of current or future air pollutant concentrations at specified receptor points resulting from the action of meteorological conditions on source emissions.

Albedo - the fraction of solar radiation reflected from the ground surface.

Ambient Air - that portion of the atmosphere, external to buildings, to which the general public has access.

Ambient Air Quality - concentration levels in ambient air for a specified pollutant and a specified averaging time period within a given geographic region.

Ambient Air Quality Standard - a level of air quality established by federal or state agencics which is to be achieved and maintained; primary standards are those judged necessary, with an adequate margin of safety, to protect the public health; secondary standards are those judged necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

AQUIP - an acronym for Air Quality for Urban and Industrial Planning, a computer-based tool for incorporating air pollution considerations into the land use and transportation planning process.

Atmospheric Boundary Layer - the lower region of the atmosphere (to altitudes of 1 to 2 km) where meteorological conditions are strongly influenced by the ground surface features.

Atmospheric Dispersion Model - a mathematical procedure for calculating air pollution concentrations that result from a specified array of emission sources and a specified set of meteorological conditions.

Average Receptor Exposure - a measure of the average impact of air quality levels on specific receptors; the measure is based on the integrated receptor exposure divided by the total number of receptors in the study region.

Background Air Quality - levels of pollutant concentrations within a study region which are the result of emissions from all other sources not incorporated in the model for the study region.

Background Emissions - the emissions inventory applicable to the background region; that is, all emission sources not explicitly included in the inventory for the study region.

Climatology - the study of long term weather as represented by statistical records of parameters such as winds, temperature, cloud cover, rainfall, and humidity which determine the characteristic climate of a region; climatology is distinguished from meteorology in that it is primarily concerned with average, not actual, weather conditions.

Concentrations - a measure of the average density of pollutants usually specified in terms of pollutant weight per unit (typically in units of micrograms per cubic meter), or in terms of relative volume of pollutant per unit volume of air (typically in units of parts per million).

Default Parameters - values associated with a parameter for a category of activities (such as heavy manufacturing) assigned to the activity parameter for a subcategory of activities (such as electrical machinery production) when the actual value for the subcategory is not known.

Degree Days - the number of degrees the average temperature is below 65° each day; used to determine demand for fuel for heating purposes.

Effective Stack Height - the height of the plume center-line when it becomes horizontal.

Emission Factor - a numerical conversion factor applied to fuel use and process rates to determine emissions and emission rates.

Emissions - effluents into the atmosphere, usually specified in terms of weight per unit time for a given pollutant from a given source.

Emissions Inventory - a data set describing the location and source strength of air pollution emissions within a geographical region.

Emissions Projection - the quantitative estimate of emissions for a specified source and a specified future time.

Equivalent Ambient Air Quality Standards - air quality levels adopted in this study to permit analysis of all air pollutants in terms of annual averages; in cases where state and federal annual standards do not exist, the adopted levels are based on the extrapolation of short period standards.

Fuel Related Sources, Fuel Emissions - fuel related sources use fuel to heat area, or to raise a product to a certain temperature during an industrial process, or for cooking in the house; they produce fuel emissions. (See also Non-Fuel Related Sources.)

Fuel Use Propensity, Fuel Demand - the total heat requirement (space heating plus process heating) determines the fuel demand; the propensity to use a particular fuel or fuels determines the actual amounts of various fuels used to satisfy the heat requirement.

Heating Requirements - the demand for fuel is specified in terms of the heating requirements:

space heating - the fuel used to heat area, such as the floor space of a school in the winter, is that required for space heating; the heat content or value of that fuel defines the space heating requirement (BTUs, British Thermal Units of heating content).

non-space heating, process heating - the fuel used to raise a product to a certain temperature during an industrial process or for cooking (with gas) in the home is that required for process heating or non-space heating. It is generally not related to outside temperature whereas space heating requirements are.

percent space heating, percent process heating - the relative proportion of a fuel or its heat content that is used for space heating or process heating defines,respectively, the percent space heating or percent process heating.

Impact Measure (or Parameter) - a quantitative representation of the degree of impact on air quality or specific receptors resulting from concentrations of specified pollutants.

Influence Region - the influence region for a study area is the geographical region containing the emission sources responsible for at least 90% of the ground level concentrations (averaged throughout the study area) of all pollutants considered.

Integrated Receptor Exposure - a measure of the total impact of air quality levels on specific receptors; the measure is based on the summation within the study region of the number of receptors times the concentration levels to which they are exposed.

Inventories - the aggregation of all fuel and process emissions sources is called the emissions inventory; the components for use with the model:

current inventory - all sources for 1969

background inventory - all sources for 1990 not directly related to the meadowlands plans.

plan inventories - all sources for 1990 related to the Meadowlands plans; this excludes any source outside the Meadowlands boundary and also excludes existing major single sources and the highway network.

Isopleth - the locus of points of equal value in a multidimensional space.

Land Use Intensity - the level of activity associated with a given land use category, for example the population density of residential areas.

Land Use Mix - the percent of total study region area allocated to specific land use categories.

Meteorology - the study of atmospheric motions and phenomena.

Microscale Air Quality - the representation of air quality in a geographical scale characterized by distances between source and receptor ranging from a few meters to a few tens of meters.

Mixing Depth - the vertical distance from the ground to the base of a stable atmospheric layer (also called inversion height).

Model Calibration - the process of correlating model projections with observed (measurements) data, usually to determine calibration factors relating predicted to observed values for each pollutant.

Model Validation - the detailed investigation of model results by comparison with measured values to identify systematic discrepencies that may be conected by alterations of model parameters or model mechanics.

Non-Fuel Related Sources, Process Emissions, Separate Process Emissions - non-fuel related sources do not burn fuel primarily for heating purposes or do not burn fuel at all; these include transportation sources, incineration, and certain industrial processes; they produce process or separate process emissions. (See also Fuel Related Sources.)

Ranking Index - a quantitative representation of the net impact on air quality or specific receptors resulting from all pollutants being considered.

Receptor - a physical object which is exposed to air pollution concentrations; objects may be animate or inanimate, and may be arbitrarily defined in terms of size, numbers, and degree of specificity of the object.

Receptor Point - a geographical point at which air pollution concentrations are measured or predicted.

Regional Air Quality - the representation of air quality in a geographical scale characterized by large areas, for example, on the order of 50 square kilometers or greater.

Schedule - number of hours per year a fuel burning activity will consume fuel; used to determine heating requirements.

Source - any stationary or mobile activity which produces air pollutant emissions.

Source Geometry - all sources for modeling purposes are considered to exist as a point, line, or area, defined as follows:

point source - a single major emitter located at a point.

line source - a major highway link, denoted by its end points.

area source - a rectangular area referenced to a grid system; includes not only area-wide sources, such as residential emitters, but single emitters and highway links deemed too small to be considered individual point or line sources by the model.

Stability Category - a classification of atmospheric stability conditions based on surface wind speed, cloud cover and ceiling, supplemented by solar elevation data (latitude, time of day, and time of year).

Stability Wind Rose - a tabulation of the joint frequency of occurrences of wind speed and wind direction by atmospheric stability class at a specific location.

Total Air Quality - the air quality at a receptor point resulting from background emission sources and from emission sources specifically within the study region.

Trapping Distance - the distance downwind of a source at which vertical mixing of a plume begins to be significantly inhibited by the base of the stability layer, and gaussian vertical distribution can no longer be assumed.

Wind Sector - a 22-1/2 degree wind direction range whose center-line is one of the sixteen points of the compass.